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CHALCOCITE ENRICHMENT.[1]

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PRELIMINARY STATEMENT.

Since 1900, when Emmons,[2] Weed,[3] and Van Hise[4] presented papers dealing with the downward enrichment of sulphide ores,[5] the subject has received, perhaps, more attention from working students of ore deposits than any other single phase in the chemistry of ore genesis. Especially with respect to the enrichment of cupriferous materials by secondary deposition the problem has been worked out to the extent that the chemical reactions involved may be indicated in a general way at least; besides which we have a fairly good understanding of the geological conditions which favor or oppose the operation of recognized processes on a scale

[1] From a forthcoming report on the geology and ore deposits of the Ely district, Nevada. Published by permission of the Director of the U. S. Geol. Survey.

[2] Emmons, S. F., "The Secondary Enrichment of Ore Deposits," *Trans. Am. Inst. Min. Eng.*, February meeting, 1900, Vol. 30, pp. 177–217, 1901.

[3] Weed, W. H., "Enrichment of Gold and Silver Veins," *Trans. Am. Inst. Min. Eng.*, February meeting, 1900, Vol. 30, pp. 424–448, 1901; "Enrichment of Metallic Veins by Later Metallic Sulphides," *Bull. Geol. Soc. Am.*, Vol. 11, pp. 179–206, 1900.

[4] Van Hise, C. R., "Some Principles Controlling the Deposition of Ores," *Trans. Am. Inst. Min. Eng.*, Vol. 30, pp. 27–127, 1901.

[5] For the bibliography of this subject the reader is referred to the following papers: Tolman, C. F., "Secondary Sulphide Enrichment of Ores," *Min. Sci. Press*, Vol. 106, pp. 180–181, 1913; Emmons, W. H., "The Enrichment of Sulphide Ores," U. S. Geol. Survey, Bull. 529, 1913.

large enough to produce the segregation of copper minerals in bodies of commercial value. The climatic conditions under which the largest or richest bodies of secondary ores have accumulated have not been adequately discussed, so that a full analysis of this portion of the subject remains to be made.

The processes of chalcocite enrichment and the conditions that control the deposition of chalcocite from oxidized copper-bearing solutions are here considered with special reference to the disseminated ores of the Ely district, Nevada, which, as mined, carry from 20 to 60 pounds of copper per ton. The principal ore bodies have been formed by the enrichment of portions of great masses of uniformly pyritized and sericitized monzonite porphyry which carry not more than half of one per cent. of copper as primary chalcopyrite. In form and occurrence the ore bodies are blankets that lie beneath an overburden or capping of fully weathered and oxidized material and grade downward into primarily mineralized rock which has not been enriched. The depth of the capping ranges from a few feet to 250 feet or more and the thickness of the material carrying the secondary chalcocite varies from a few feet up to a maximum of about 400 feet. The ores contain from 5 to perhaps 10 per cent. of metallic sulphides, of which usually somewhat more than half is pyrite. Both chalcopyrite and pyrite have been partly replaced by chalcocite, but the coatings of this secondary mineral are commonly much deeper on the chalcopyrite than on the pyrite, much of which has not been coated at all. The principal nonmetallic minerals—quartz, orthoclase, sericite, and brown mica—are the same as those of the pyritized rock from which the ores have been derived. All these minerals persist in the weathered capping, though usually the brown mica has been bleached and a little kaolin formed, mainly through the decomposition of the orthoclase.

The chemistry of downward chalcocite enrichment may be treated by following in imagination the various incidents of the journey made by rainwater which, falling on the surface, soaks into the ground and penetrates an existing ore body. Rainwater

carries in solution the various gases of the air, including oxygen and carbon dioxide. In arid and semi-arid regions it contains also noteworthy amounts of common salt, which may be regarded as of wind-blown origin. As these waters pass into the soil and into the porous weathered capping that lies above the ore mass they come into contact with orthoclase and mica and with oxidic compounds of iron and copper (including limonite and its congeners), basic sulphates carrying iron or copper, and basic carbonates of copper. Metallic copper and red oxide cuprite are also fairly common in the overburden. The silicate minerals in the capping tend to make the water alkaline,[1] but as they are only slightly attacked this tendency is likewise slight. Of the metallic minerals in the capping, those containing sulphate decompose, being somewhat soluble, the final result being to produce and to leave in place insoluble limonite and copper carbonates and to furnish small amounts of iron and potash sulphates to the solution. Thus far the dissolved oxygen does not enter largely into reaction because most of the minerals of the capping are already fully oxidized. The only exceptions to be noted are cuprite and native copper. Also, the carbonic dioxide has been by no means exhausted.

Everywhere the capping colored characteristically red by ferric iron compounds gives place by a short transition to gray or bluish ore. Above this horizon the waters are able to accomplish little in addition to what had been done in advance by similar waters. Just beneath the capping the solution encounters material rich in sulphide minerals, that are subject to ready oxidation. Here then chemical action between the oxygenated waters and the sulphide minerals ensues, a series of reactions being initiated of which series the culminating reactions involve the deposition of chalcocite. At first the waters contain free sulphuric acid furnished by the decomposition of pyrite, but gradually the acid becomes neutralized by bases furnished by the gangue minerals, and at sufficient depth the solutions become alkaline. If considered

[1] Cameron, F. K., and Bell, J. M., Bull. No. 30, Bureau of Soils, U. S. Dept. of Agriculture, p. 12 et seq., 1905; Clark, F. W., "The Data of Geochemistry," Bull. 491, U. S. Geol. Survey, pp. 454-459, 1911.

with respect to the minerals decomposed the reactions that occur beneath the capping present a succession of oxidations, whereas if considered with respect to the active solution, the changes are of course as consistently in the direction of reduction. The reactions may be considered in three groups, assignable in a general way to higher, intermediate, and lower positions in the body of sulphide-containing material. In the upper part of a sulphide ore body, where atmospheric oxygen is the oxidizing agent; somewhat lower down, where free oxygen has been exhausted ferric sulphate becomes active; and after the oxygen made available by this carrier has been utilized cupric sulphate furnishes oxygen. The action of cupric sulphate on pyrite and chalcopyrite results in the deposition of chalcocite and the consequent enrichment of material carrying the primary sulphides. The formation of secondary chalcocite probably involves a series of transitions or stages, as pyrite—chalcopyrite—bornite—covellite—chalcocite.

The following discussion is incomplete in that the chemistry of the copper minerals that are characteristic of the capping is not considered. Though oxidation in the portion of an ore body that lies just beneath the capping results in the compounding of cupriferous solutions the fact must not be neglected that here also are formed the relatively stable basic carbonates and sulphates, and the even more stable minerals cuprite and metallic copper.

EXPERIMENTAL DATA ON CHALCOCITE DEPOSITION.

Winchell[1] and Tolman, and also Read[2] obtained coatings of chalcocite by treating pyrite with slightly acid cupric sulphate solution in the presence of SO_2. In experimental work conducted at a temperature of about 200° C. Stokes[3] induced the formation of cuprous and cupric sulphides by treating pyrite with

[1] Winchell, H. V., *Bull. Geol. Soc. Am.*, Vol. 14, pp. 269–276, 1903.

[2] Read, T. T., "Secondary Enrichment of Copper-iron Sulphides," *Trans. Am. Inst. Min. Eng.*, Vol. 37, pp. 297–303, 1906.

[3] Stokes, H. N., "On Pyrite and Marcasite," Bull. U. S. Geol. Survey No. 186, p. 44, 1900; "Experiments on the Solution, Transportation, and Deposition of Copper, Silver, and Gold," ECON. GEOL., Vol. 1, pp. 644–650, 1906.

cupric sulphate solution slightly acidified with sulphuric acid. The work of Stokes was followed by that of Read already mentioned, and by noteworthy observations by Sullivan. Pulverized pyrite[1] and chalcopyrite shaken in a dilute solution of copper sulphate caused the solution to lose its color. By contact with 20 grams of pyrite during three days 40 cm. of cupric sulphate solution lost .04 grams of copper out of .097 grams originally present.

The experiments of Sullivan are important because they show that pyrite and chalcopyrite can cause the precipitation of copper from sulphate solution at ordinary temperatures without the intervention of a strong reducing agent such as was used by Winchell, and it is sufficiently obvious that the insoluble compound formed must be a sulphide. But the action is ordinarily so reluctant that investigators of the subject have usually failed to get visible coatings on pyrite or chalcopyrite as the result of treatment in the cold with simple solutions of cupric sulphate. However, by subjecting fragments of chalcopyrite to the action of a weak solution of cupric sulphate during three months, Welsh[2] and Stewart obtained both a tarnish, having the purple tinge of bornite, and "some thin black films."

The writer has found that bornite reacts readily with cupric sulphate and that indigo coatings may be formed on that mineral in a few hours by simply immersing it in a solution of the copper salt. Under prolonged treatment the indigo colors first developed changes to a steely blue which gradually fades until it gives place to the gray color which is so characteristic of chalcocite. Attempts to obtain similar results with chalcopyrite were not successful when cupric sulphate was used alone, but in the presence of ferrous sulphate this mineral soon becomes tarnished and passes through a series of color changes which repeated observation has shown to occur in a definite and predictable order. First

[1] Sullivan, E. C., "Discussion Relating to the Formation of Secondary Copper Sulphides in Criticism of Read's Paper," *Trans. Am. Inst. Min. Eng.*, Vol. 37, p. 894, 1907.

[2] Welsh, T. W. B., and Stewart, C. A., "Note on the Effect of Calcite Gangue on the Secondary Enrichment of Copper Veins," ECON. GEOL., Vol. 7, pp. 785–787, 1912.

the natural yellow of the mineral darkens slightly, then the surface becomes brownish with a bronzy tone, then pink, light purple, darker purple, indigo, and various shades of steely blue with gradually lessening depth. The final result is a gray coating of metallic luster which turns blue under the Stokes[1] test for chalcocite. Between the blue and gray stages the surface of the mineral becomes yellowish or bronzy, the appearance being as though the film first developed had been dissolved. In various trials the whole transition has required from five to ten days, and in certain trials the final chalcocite stage was not attained at all. The same succession of colors, except the apparent reversion to chalcopyrite, may be obtained by another method which will be described further on. By means of a mixed copper and iron solution spots of blue resembling covellite may be developed on pyrite within a few hours, but so far as observed this mineral does not become uniformly coated, as does chalcopyrite. When the natural acidity of a solution containing cupric sulphate was increased by adding a little sulphuric acid, chalcopyrite remained untarnished at the end of four months, and Winchell states that pyrite fragments immersed in acidified cupric sulphate solution showed no visible alteration at the end of two years.

While both bornite and chalcopyrite have been artificially coated with gray chalcocite films, the gray coatings have been preceded in all successful experiments by indigo-colored films which are regarded as covellite. An unsuccessful attempt was made to form chalcocite directly by treating granulated bornite with a solution containing ferrous sulphate in molecular concentration about four times that of cupric sulphate. In this experiment the ferrous sulphate solution was freshly reduced. The mineral and the liquids employed were freed from air by ebullition under reduced pressure at 60° C. The apparatus was sealed under exhaust and was cooled before the reagents were brought into contact with the mineral. After the lapse of about four days the bornite had assumed a deep indigo color which is taken to indicate

[1] A fragment of chalcocite boiled for a moment with 10 per cent. ferric sulphate solution turns blue. ECON. GEOL., Vol. 1, p. 23, 1903.

the development of covellite. After three weeks had passed the general tone of the granular powder was gray, but some of the grains still had blue surfaces. At the end of three months the material was removed from the apparatus for examination. Under the microscope most of the grains had the appearance of chalcocite but certain surfaces showed the color of covellite. A sample of the original mineral was found to contain a small amount of chalcopyrite and specks of covellite, the latter being present in about the same proportion as in the treated material. It therefore appears that the bornite and chalcopyrite were both coated with chalcocite whereas the original covellite remained unaltered. Like results were attained in a solution that carried equivalent concentrations of copper and iron. In both experiments the concentration of the copper salt was about .02 of the formula weight of cupric sulphate. Natural covellite was treated with solutions of corresponding composition but no change of color had resulted at the end of four months.

The foregoing observations have led to the suggestion that the change of pyrite or chalcopyrite to chalcocite may be considered as an alteration involving a series of steps, or perhaps even a continuous progression through indefinite compounds or mixtures of iron-copper sulphides.[1] Discussion of the suggested change pyrite to chalcopyrite is not offered for lack of adequate basis furnished by experiment or observation. On the other hand, the change chalcopyrite through bornite and covellite to chalcocite may be brought about artificially in various ways, some of which have been already noted, and so far as the writer's experiments have gone it seems to be impossible to change chalcopyrite to chalcocite without traversing the bornite and covellite stages, or to convert bornite into chalcocite except through covellite as an intervening product. Still it seems probable that in nature the covellite stage may not always enter into the series, though the chemical environment which would favor the more direct change to chalcocite can not be stated definitely at present. Experimental results with bornite and cupric sulphate indicate that the change covellite to chalcocite may occur and there is a strong suggestion that the

[1] See table on page 638.

transformation proceeds in such a way that graduated mixtures of CuS and Cu_2S are formed. This suggestion is supported by Graton and Murdock who have noted that natural "chalcocite" is not always gray in color but shows various shades of steely blue such as might result from minute intergrowth of chalcocite and covellite.

Specimens of copper ore described by Graton and Murdock[1] contain the series pyrite, chalcopyrite, bornite, covellite, and chalcocite, the mutual space relations of the several minerals being such that each mineral of higher copper content appears to have been derived from the alteration of the mineral next below it in the series. Graton and Murdock state that all these minerals[2] have been observed by them as described in different parts of a single polished specimen, under examination by means of the reflecting microscope, but that all the copper-bearing phases were not noted about any single grain of pyrite. Mr. Bastin, of the Geological Survey, has shown the writer a specimen of copper ore from Gilpin County, Colorado, which represents partly altered chalcopyrite. Certain surfaces show chalcocite apparently lying directly on the chalcopyrite. On the other surfaces, and evidently of later origin, are complex films with covellite outside and a substance resembling bornite beneath. In different places may be noted bronzy effects, grading in tone from the normal color of bornite to a purple hue intermediate between bornite and covellite, as though bornite had been plated over with a transluscent film of the indigo mineral. Similar color effects are to be obtained, according to Read,[3] by treating chalcopyrite with copper sulphate solution in the presence of SO_2.

"The enriched sulphide was dark green in color; during the month it had become successively bronzy, purple, and dark steely blue."

This statement is open to the interpretation that the surface

[1] Graton, L. C., and Murdock, Joseph, "The Sulphide Ores of Copper," *Trans. Am. Inst. Min. Eng.*, Vol. 4, pp. 754–755, 1913.

[2] Compare relations of bornite as described by R. H. Sales, ECON. GEOL., Vol. 5, p. 682, 1910.

[3] Read, T. T., "Secondary Enrichment of Copper-iron Sulphides," *Trans. Am. Inst. Min. Eng.*, Vol. 37, p. 300, 1907.

of the film deposited on the chalcopyrite passed through the stages bornite and covellite and that some chalcocite was formed.

The colors observed by Read and present in the Gilpin County specimen referred to above may be readily obtained by another simple procedure, and the observer can hardly fail to conclude that the colors obtained indicate the formation of the minerals bornite, covellite, and chalcocite. If any member of the series chalcopyrite, bornite, covellite is touched by a piece of iron while it is immersed in a cupric sulphate solution the mineral changes color almost instantly, and in a short time becomes coated with the mineral next above it in the series. The brilliant indigo of covellite changes to the dull gray so characteristic of chalcocite, bornite assumes a blue color unmistakably like that of covellite, and chalcopyrite takes on a bronzy hue resembling that of bornite. Furthermore, within a very short time the bronze plating on chalcopyrite gives place to or is hidden by a film of covellite; then within an hour or so the surface turns to a chalcocite gray, and finally metallic copper is deposited. When pyrite is used in place of a cupriferous sulphide the effect of the iron is sufficient to throw down metallic copper rather quickly, but by scraping away the metal and again placing the mineral in contact with iron in the solution it is possible to obtain deposits of copper sulphides. In this way spots having somewhat the same color as chalcopyrite and others bronzy like bornite may be developed on pyrite along with unmistakable films of covellite and of chalcocite. If copper is used instead of iron the results are essentially the same with chalcopyrite, bornite and covellite. For instance, covellite may be coated with chalcocite by contact with copper in a solution of cupric sulphate. It is obvious that the speed of reaction may be varied by employing different metals as inductors, or by employing minerals to cause electrolytic action. Very pleasing results have been obtained by placing in a solution of cupric sulphate a polished specimen of intergrown chalcopyrite and pyrrhotite. Here a pinkish bronze color resembling that of bornite appeared within a few days but gradually changed to purple, deep purple and finally to indigo-blue. On the most reactive grains the covel-

lite color was fully developed in about eight weeks, but the surface in general became blue only after 12 weeks, and even then certain areas were still bronzy. At the end of four months no gray color had developed to indicate the formation of chalcocite, but the color was a paler blue than that of natural covellite.

It may be suggested that the results described, which were obtained under ordinary temperatures, may actually epitomize the course of reaction between the primary sulphides and copper salts held in oxidized solutions penetrating from the surface. Even if the means employed to produce the results in a short time are not comparable with those involved in natural processes, perhaps the conditions under which the experiments were made may be considered to be less unnatural than those prevailing in mineral syntheses effected under high temperatures.

Since in nature coatings of covellite and of chalcocite are found on grains of pyrite without observable films of other members of the series between the primary and the secondary mineral, the contention might be made that intermediate products have not been involved in the change, and that the suggested step process is therefore disproved. This conclusion does not necessarily follow, because intermediate phases may exist in films too thin to be observed, or if formed may have disappeared through conversion into some mineral standing higher in the series. However, this may be, it would seem that the true course of the chemical action between pyrite and chalcopyrite on the one side and cupric sulphate on the other can be determined by sufficiently detailed investigations in extension of the experiments made by Sullivan which are referred to on page 625. In future work the effects of ferrous and ferric sulphates and of sulphuric acid in known concentrations should be determined.

SOURCE OF OXYGEN.

Before taking up the threefold series of reactions leading to chalcocite deposition, it is of interest to inquire whether the oxygen dissolved in rainwater could alone have effected the oxidation of

the mass of material which has contributed the secondary copper now contained in any given ore body. This query may be answered in the negative. The ore body at Copper Flat, assumed to average 1.5 per cent. copper, carries as much added or secondary copper as could be furnished by the complete leaching of 400 feet of primary material containing one half of one per cent. copper: but with about 100 feet of existing cap rock still containing at least one half per cent. copper in oxidic minerals, the total depth of material which has been oxidized to produce the present mass of chalcocite ore can not have been less than 500 feet. It is assumed that all of this 500 feet of material passed through the chalcocite stage, so that a goodly part of the copper has been several times dissolved and redeposited. This being true, the amount of oxygen required would be the same as the amount necessary to oxidize 500 feet of ore such as now exists. By considering the amount of oxygen that water can absorb by contact with the air under atmospheric pressure at 7,000 feet elevation, and at the present mean annual temperature of the region, it is found that, even allowing that precipitation in the past has been 25 per cent. greater than at present, and that so much as 60 per cent. of the rainfall could have penetrated to the ore body, the oxygen required to oxidize 500 feet of ore like that now existing would require the contributions of rainfall during a longer period than physicists and geologists are willing to allow for the entire history of the earth.[1] Although all the assumptions made tend to a minimum, the time required, as calculated in this way, is still so inordinately great as to demand a different hypothesis in regard to the manner in which oxygen has been delivered to the place of sulphide decomposition. It is thought therefore that a large part of the oxygen must have been derived from air that circulated through the oxidized capping. The pore space in this material amounts to more than 10 per cent. of the total bulk of the rock and there can be no doubt that when the cellular openings

[1] Becker, G. F., "The Age of the Earth," Smithsonian Misc. Coll., Vol. 56, No. 6, pp. 1–28, 1910. This is the most recent review of various estimates by different methods. Dr. Becker regards 60 million years as the figure most nearly in accord with the data now in hand.

are not water-filled they must be occupied by air. It would seem then, that the greater part of the oxidation must take place during such times as the sulphides are merely moist rather than when they are flooded, because then the water could receive oxygen from the air in contact with it at the same rate at which oxygen is being taken out of solution by the reactions of oxidation. Thus the water would remain saturated under the conditions of partial pressure pertaining to the proportions of various gases contained in the subterranean air. Within a short distance beneath the completely oxidized and porous capping the rock becomes much less pervious, and here the solutions would be present only as capillary films essentially filling the interspaces and therefore leaving no room for air to penetrate. The train of reasoning may be carried one step farther. Even if some air does penetrate the sulphide ore body the circulation would be comparatively sluggish, and since all of the supply must pass by the sulphides in process of oxidation it is apparent that the oxygen might be entirely depleted, so that the gases reaching the ore mass would be merely the inert constituents of the atmosphere plus carbon dioxide.

OXIDATION BY FREE OXYGEN.

Beneath the capping the sulphides first encountered by waters that carry dissolved oxygen are pyrite and chalcopyrite. Just at the top of any porphyry ore body grains of these minerals persist after the removal of chalcocite coatings which they carried at a time when the bottom of the capping was slightly higher than at present. Here too is to be found some pyrite which never carried more than the slightest coating of chalcocite.

The sulphides named are of course readily decomposed by the oxygen-bearing solution. The partial oxidation of pyrite with ferrous sulphate as a product has been indicated by Gottschalk and Buehler[1] by means of the two equations:

$$FeS_2 + 4O = FeSO_4 + S,$$
$$FeS_2 + 6O = FeSO_4 + SO_2.$$

[1] Gottschalk, V. H., and Buehler, H. A., "Oxidation of Sulphides," ECON. GEOL., Vol. 7, p. 16, 1912.

The complete oxidation of pyrite may be considered as taking place in some such manner as is outlined by the foregoing equations and the following series,[1] in which equation (3) is derived from (1) and (2).

$$FeS_2 + 7O + H_2O = FeSO_4 + H_2SO_4, \quad (1)$$
$$2FeSO_4 + O + H_2SO_4 = Fe_2(SO_4)_3 + H_2O, \quad (2)$$
$$FeS_2 + 15O + H_2O = F_2(SO_4)_3 + H_2SO_4. \quad (3)$$

For chalcopyrite, equations essentially analogous to (1) and (3) are:

$$CuFeS_2 + 8O = FeSO_4 + CuSO_4, \quad (1a)$$
$$2CuFeS_2 + 16O + H_2SO_4 = Fe(SO_4)_3 + CuSO_4 + H_2O. \quad (3a)$$

Part of the ferric sulphate formed at the upper surface of the body where free oxygen is present decomposes to form basic iron sulphates and hydrated iron oxide, another part may be supposed to pass downward in solution and to attack pyrite, chalcopyrite, and chalcocite. The formation of iron hydroxide may be represented in various ways, for example as follows:

$$6FeSO_4 + 3O + 3H_2O = 2Fe_2(SO_4)_3 + 2Fe(OH)_3.$$

The equations which have been given indicate that the decomposition of pyrite yields sulphuric acid, and ferric sulphate. Under natural conditions, solutions carrying these substances come into contact with chalcocite only a short distance below the point where pyrite and chalcopyrite are first encountered. Here, if any free oxygen remains, chalcocite is decomposed with the formation of cupric sulphate:

$$Cu_2S + H_2SO_4 + 5O = 2CuSO_4 + H_2O. \quad (4)$$

[1] Compare Stokes, H. N., "On Pyrite and Marcasite," Bull. No. 186, U. S. Geol. Survey, pp. 15 and 19, 1901; Lindgren, W., "Copper Deposits of Clifton-Morenci District," Prof. Paper U. S. Geol. Survey No. 43, p. 179, 1905. This author gives an extended bibliography relating to pyrite oxidation. Allen, E. T., "Sulphides of Iron and their Genesis," *Min. Sci. Press*, Vol. 103, pp. 413–414, 1911; Gottschalk, V. H., and Buehler, H. A., "Oxidation of Sulphides," ECON. GEOL., Vol. 7, p. 16, 1912; Tolman, C. F., "Secondary Sulphide Enrichment of Ores," *Min. Sci. Press*, Vol. 42, p. 40, 1913.

The reaction indicated by this equation may be considered as using up the last of the free oxygen which can reach a body of enriched porphyry ore under ordinary conditions. At points immediately below those where the free oxygen has been entirely consumed, ferric sulphate and cupric sulphate are present. Both these compounds are capable of oxidizing the sulphides, but the former is more readily reduced than the latter, and it may be supposed to undergo almost complete reduction to ferrous sulphate before the latter can come into play as an oxidizing agent.

OXIDATION BY FERRIC SULPHATE.

Where chalcocite and the other sulphides occur together, and especially where, as in the Ely ore bodies, the chalcocite is in actual contact with pyrite or chalcopyrite in the form of coatings, it is the first mineral to be attacked by ferric sulphate and it acts as a temporary protection against the decomposition of these minerals. The latter point has been proved experimentally by Gottschalk and Buehler[1] and fully confirmed by Wells.[2]

According to Vogt[3] the action of ferric sulphate on chalcocite, which would come into play below the shell of nearly complete oxidation is as follows:

$$Cu_2S + 2Fe_2(SO_4)_3 = 4FeSO_4 + 2CuSO_4 + S. \qquad (5)$$

But if the sulphur set free reacts with more ferric sulphate, SO_2 might be formed and with still more ferric sulphate sulphuric acid will result, and eventually we may arrive at the equation suggested by Weed,[4] which may be deduced from equations (5), (7), and (8):

$$Cu_2S + 4H_2O + 5Fe_2(SO_4)_3 = 10FeSO_4 + 4H_2SO_4 + 2CuSO_4. \qquad (5a)$$

[1] Gottschalk, V. H., and Buehler, H. A., ECON. GEOL., Vol. 7, p. 31, 1912.

[2] Wells, R. C., "Electrical Potentials between Conducting Minerals and Solutions," *Jour. Wash. Acad. Sci.*, Vol. 2, pp. 514–516, 1912.

[3] Vogt, J. H. L., "Problems in the Geology of Ore Deposits," *Trans. Am. Inst. Min. Eng.*, Vol. 31, p. 166, 1902.

[4] Weed, W. H., "Enrichment of Gold and Silver Veins," *Trans. Am. Inst. Min. Eng.*, Vol. 30, p. 429, 1901.

Equation (5*a*) may be regarded also as summarizing a series of oxidation steps such as the following:

$$Cu_2S + Fe_2(SO_4)_3 = CuS + 2FeSO_4 + CuSO_4,$$
$$CuS + Fe_2(SO_4)_3 = S + 2FeSO_4 + CuSO_4,$$
$$S + Fe_2(SO_4)_3 = 2SO_2 + 2FeSO_4,$$
$$4H_2O + 2SO_2 + 2Fe_2(SO_4)_3 = 4H_2SO_4 + 4FeSO_4.$$

The same reagent, ferric sulphate, may be considered as acting on pyrite in a manner represented more or less adequately by the following group of equations where equation (9) is derived by means of equations (6) to (8).

$$FeS_2 + Fe_2(SO_4)_3 = 3FeSO_4 + 2S, \quad (6)$$
$$S + Fe_2(SO_4)_3 = 2FeSO_4 + 2SO_2, \quad (7)$$
$$SO_2 + Fe_2(SO_4)_3 + 2H_2O = 2FeSO_4 + 2H_2SO_4, \quad (8)$$
$$FeS_2 + 7Fe_2(SO_4)_3 + 8H_2O = 15FeSO_4 + 8H_2SO_4. \quad (9)$$

It is to be noted that equation (9) is comparable with equation (1). For chalcopyrite an expression similar to (9) is:

$$CuFeS_2 + 8Fe_2(SO_4)_3 + 8H_2O = 17FeSO_4 + 8H_2SO_4 + CuSO_4 + . \quad (9a)$$

In the study of places in the ore pits where the decompositions indicated above are in progress the observer must remark the short space that intervenes between capping fully oxidized and the subjacent ore wherein to casual observation chalcocite shows no sign of having been attacked. In so far as the decomposing power of the downward moving waters depends upon the presence of free oxygen that power appears in general to be almost spent within a shell of material scarcely more than three feet thick, though a certain amount of impoverishment may be going on to a considerably greater depth through the action of ferric sulphate upon chalcocite (see equations (5) and (5*a*)). It should be noted, of course, that the under surface of the oxidized capping is very irregular: as a natural result of fractures in the ore mass. A cross section of the surface between the capping and the ore resembles the exaggerated profile comparing mountain heights which is to be found in our older school geographies.

PARTIAL RESUMÉ.

The foregoing discussion should make clear the following points. First, that waters from the surface penetrating a body of porphyry ore will continue to decompose strongly the metallic sulphides present so long as they contain or can acquire free oxygen, or so long as they contain ferric sulphate. Second, that where chalcocite, pyrite, and chalcopyrite are all present the chalcocite will be largely and perhaps fully decomposed before the other minerals are attacked. Third, that the decomposition of chalcocite, pyrite, and chalcopyrite effects the reduction of ferric salts contained in the solution. Fourth, that the decomposition of pyrite, chalcopyrite, and chalcocite each tends to produce sulphuric acid. Fifth, that the decomposition of chalcocite and of chalcopyrite furnish cupric sulphate to the solution. Briefly then, when oxygen-bearing waters reach the upper part of the mass of sulphide-bearing rock the consumption of the dissolved oxygen begins at once, and before the waters can progress downward for any considerable distance all of this free oxygen is used up in decomposing the sulphides. Also within a short distance, ferric sulphate is largely reduced to ferrous sulphate. So long as free oxygen is present the decomposition of chalcocite will progress until no sulphuric acid remains uncombined. It should be added that cuprous and ferric irons are always present in small concentration[1] in any solution containing cupric and ferrous sulphates.

OXIDATION BY CUPRIC SULPHATE.

The progress of the surface derived waters has been followed to the point where they contain no free oxygen and only a minor amount of ferric sulphate, but where they carry ferrous sulphate, cupric sulphate, and sulphuric acid. Thus far on its downward journey it may be assumed that the cupric sulphate has been pro-

[1] Stokes, H. N., "Experiments on the Solution, Transportation, and Deposition of Copper, Silver, and Gold," ECON. GEOL., Vol. 1, pp. 644–650, 1906; Wells, R. C., "Discussion on Secondary Enrichment," ECON. GEOL., Vol. 5, pp. 481–482, 1910.

tected from reduction because at ordinary temperatures and in acid solution it is less readily reduced than ferric sulphate.[1]

Beyond the place where the ferric sulphate concentration in the solution has been reduced to a certain minimum, cupric sulphate comes into play as an oxidizing agent. The sulphides with which the solution comes into contact are chalcocite, chalcopyrite, and pyrite. At ordinary temperatures in the absence of oxygen, dilute sulphuric acid does not decompose chalcocite, and Wells[2] has shown that chalcopyrite and pyrite are probably not attacked under the same conditions. It is to be noted, however, that at high temperatures cupric sulphate reacts with chalcocite[3] to form covellite and cuprous sulphate, and on cooling the latter decomposes, a product of its decomposition being metallic copper. On the other hand it would appear that cupric sulphate does attack chalcopyrite and pyrite at ordinary temperatures, so that iron passes into solution as ferrous sulphate, sulphuric acid is formed, and a copper sulphide is deposited. The last part of this statement is supported by the fact that covellite and chalcocite are common products in nature where copper sulphate solutions from the upper zone of oxidation have encountered pyrite and chalcopyrite. Although very little quantitative laboratory work has been done in connection with this subject, the work of Stokes[4] has furnished two equations which aim to represent the changes pyrite to covellite and pyrite to chalcocite in molecular proportions.

The Stokes equation for chalcocite formed by replacement of pyrite through the action of cupric sulphate may be built up empirically by the method which has been used in the derivation of equations (3) and (9) (see pp. 633 and 635). Thus:

$$2FeS_2 + 2CuSO_4 = Cu_2S + 2FeSO_4 + 3S,^{5}$$

[1] Stokes, H. N., ECON. GEOL., Vol. 1, p. 646, 1906.

[2] Record of experiments given by E. H. Emmons, Bull. U. S. Geol. Survey No. 529.

[3] Stokes, H. N., *loc. cit.*, p. 648.

[4] Stokes, H. N., "Experiments on the Action of Various Solutions on Pyrite and Marcasite," ECON. GEOL., Vol. 2, pp. 15–23, 1906.

[5] Vogt, J. H. L., "Problems in the Geology of Ore Deposits," *Trans. Am. Inst. Min. Eng.*, Vol. 31, p. 166, 1902.

$$3S + 2CuSO_4 = Cu_2S + 4SO_2,^1$$
$$6H_2O + 5SO_2 + 2CuSO_4 = Cu_2S + 6H_2SO_4,$$
$$12H_2O + 5FeS_2 + 14CuSO_4 = 8Cu_2S + 5FeSO_4 + 12H_2SO_4. \quad (10)^2$$

In a similar manner the following equation indicating the replacement of pyrite by covellite may be deduced:

$$4H_2O + 4FeS_2 + 7CuSO_4 = 7CuS + 4FeSO_4 + 4HSO_4. \quad (11)^3$$

As thus derived each of the Stokes equations appears to summarize a succession of oxidation effects. It is probable that the complete reactions involve several steps, including the temporary formation of chalcopyrite and perhaps the progressive formation of several mineral species intermediate in composition between chalcopyrite and chalcocite. The minerals of what may be called the pyrite-chalcocite series are given in the following table in which the order is that of increasing copper content.

PYRITE-CHALCOCITE SERIES.

Mineral.	Formula.	Constitution According to Hintze.
Pyrite	FeS_2	. . . . .
Chalcopyrrhotite	$CuFe_4S_6$	$(FeS_2)_2(Fe, Cu'')_2$
Barracanite	$CuFe_2S_4$	$(FeS_2)_2Cu''$
Cubanite	$CuFe_2S_3$	$FeS_2(FeCu')$
Chalcopyrite	$CuFeS_2$	$Cu_2SFe_2S_3$
Barnhardtite	$Cu_4Fe_2S_5$	$2Cu_2SFe_2S_3$
Bornite[3] (1)	Cu_3FeS_3	$3Cu_2SFe_2S_3$
Bornite (2)	Cu_5FeS_4	$5Cu_2SFe_2S_3$
Bornite (3)	Cu_9FeS_6	$9Cu_2SFe_2S_3$
Covellite	CuS	CuS
Chalcocite	Cu_2S	Cu_2S

No discussion of the minerals standing between pyrite and

[1] As intermediate between this equation and the one foregoing the following reaction should be considered: $4H_2O + 6CuSO_4 + S = 3Cu_2SO_4 + 4H_2SO_4$. See Stokes, *op. cit.*, p. 44.

[2] Stokes, *op. cit.*, p. 22.

[3] Hintze, "Handbuch der Mineralogie," gives the three formulas here presented in his discussion of bornite. The second formula is the one adopted by B. J. Harrington, *Am. Jour. Sci.*, 4th ser., Vol. 16, p. 151, 1903.

chalcopyrite in the table is here attempted, but it may be suggested that the other iron-bearing members of the series are formed successively as stages in the production of covellite or chalcocite through the action of cupric sulphate upon pyrite or chalcopyrite. The basis for this suggestion is given in a foregoing section. Here the contemplated change pyrite to chalcopyrite, though not yet adequately verified by experimental work, may be indicated by an equation which is readily deduced by the method employed in arriving at equation (10):

$$8H_2O + 8FeS_2 + 7CuSO_4 = 7CuFeS_2 + FeSO_4 + 8H_2SO_4. \quad (12)$$

Next for the changes chalcopyrite to chalcocite and to covellite we may have summary equations analogous to (10) and (11) thus:

$$8H_2O + 5CuFeS_2 + 11CuSO_4 = 8Cu_2S + 5FeSO_4 + 8H_2SO_4, \quad (13)$$

$$CuFeS_2 + CuSO_4 = 2CuS + FeSO_4. \quad (14)$$

Equation (13) and analogous expressions, which may be deduced to indicate the same final products where barnhardtite or any member of the bornite group is taken as the mineral undergoing replacement, are all reducible to a single expression in which the active part of the mineral molecule is considered to be solely the iron sulphide which it contains. Equation (13) may be written thus:

$$16H_2O + 5Cu_2S\ Fe_2S_3 + 22CuSO_4 = 5Cu_2S + 11Cu_2S + 10FeSO_4 + 16H_2SO_4.$$

As the expression suggests that $5Cu_2S$ has undergone no change we have by subtraction:

$$16H_2O + 5Fe_2S_3 + 22CuSO_4 = 11Cu_2S + 10FeSO_4 + 16H_2SO_4. \quad (15)$$

Finally by algebraically combining equations (10) and (11) or equations (13) and (14) so as to eliminate FeS_2 from the first

or $CuFeS_2$ from the second pair, an expression is found for the conversion of covellite into chalcocite, or the reverse:

$$4H_2O + 5CuS + 3CuSO_4 \rightleftharpoons 4Cu_2S + 4H_2SO_4. \qquad (16)$$

Presented in this essentially empirical way the chemistry of the secondary copper sulphides centers about the three reactions represented by equations (12), (15), and (16), and these reactions are therefore regarded as particularly worthy of investigation by quantitative work in the chemical laboratory.

ALTERATION OF COVELLITE TO CHALCOCITE.

The supposed change covellite to chalcocite under the action of cupric sulphate (equation 16) has not been established by experiments in which essentially pure natural covellite was used, but as already stated the transition ensues where bornite which has been coated with covellite is further treated with cupric sulphate solution, and the change in color from indigo to gray takes place more quickly in a solution already containing ferrous sulphate in addition to cupric sulphate. The experiment described on page 625 was devised with the expectation that chalcocite would be directly formed without the intervening covellite stage. This expectation was based upon the known reversible reaction between ferrous and cupric sulphates which produces cuprous and ferric ions in the solution:

$$2CuSO_4 + 2FeSO_4 \rightleftharpoons Cu_2SO_4 + Fe_2(SO_4)_3.^1$$

While chalcocite was not directly formed, the observed hastening of the final chalcocite stage strongly suggests that the relative concentrations of cupric and ferrous salts in the downward moving solution may be one of the principal factors in determining whether covellite or chalcocite is to be the end stage in the sulphide enrichment of copper ores. In this experiment the

[1] Stokes, H. N., "On Pyrite and Marcasite," Bull. U. S. Geol. Survey No. 186, pp. 44-45, 1901. This reversible reaction was studied by Stokes, who says: "It is doubtless to the reduction of the cupric sulphate by sulphur and by ferrous sulphate that the formation of chalcocite from pyrite is to be ascribed."

color change from covellite-blue to chalcocite-gray occurs by gradation through steely-blue. The possible import of this succession of colors which is observed also when natural covellite is touched by iron or copper while immersed in a cupric sulphate solution has been discussed on page 627.

In addition to the experiments with bornite, the attempt was made to change covellite to chalcocite by treating it with a mixture of cupric and ferrous sulphate. In each of three experiments one gram of powdered covellite was treated in sealed tubes with about 55 cm.^{3} of solution from which all air had been exhausted. In one experiment the strength of the solution with respect to copper was about .02 F.,[1] and with respect to iron .17 F.; in another experiment copper .02 F.; iron .017 F.; while in the third experiment no cupric sulphate was used, ferrous sulphate being present in about .09 F. concentration. At the end of three months the mineral showed no notable change in color in any of the tubes. Chalcocite similarly treated with ferrous sulphate solution also remained apparently unchanged.

If the reaction contemplated by equation (16) when read from left to right could be established, the result would be of noteworthy importance in the theory of chalcocite deposition.

$$H_2O + 5CuS + 3CuSO_4 \rightleftharpoons 4Cu_2S + 4H_2SO_4.$$

Inspection of this expression indicates that in a solution already containing sulphuric acid in any considerable concentration, covellite, rather than chalcocite, would be the stable mineral. In other words, a solution of relatively high acidity would tend to the formation and persistence of covellite while decreasing acidity would favor deposition of chalcocite. Thus, theoretically considered, it follows also that where silicate or carbonate minerals are present to take up free sulphuric acid, chalcocite would be the more stable of the two sulphides, a conclusion which is in harmony with the very considerable aggregate loss of bases during the alteration of pyrite porphyry through chalcocite ore to the leached and fully oxidized capping, and also with the observed alkaline reaction of the Brooks mine water.

[1] Here the symbol F. is used to indicate formula weight.

VOLUME RELATIONS IN CHALCOCITE DEPOSITION.

The replacement of pyrite by chalcocite, if considered as taking place according to equation (10), would involve a material increase in volume, whereas the corresponding replacement of chalcopyrite by chalcocite according to equation (13) would occur with a slight decrease in volume. Definite figures can not, of course, be given to represent these theoretical changes in volume but if the limits are calculated[1] the figures for pyrite to chalcocite show expansion ranging between 54 and 75 per cent., while those for chalcopyrite to chalcocite show contraction ranging from 6 to 15 per cent. From this it would appear that the replacement of chalcopyrite by chalcocite would take place more readily than the replacement of pyrite by chalcocite if cupric sulphate is the only reagent in the solution to be considered. That chalcopyrite is actually more susceptible than pyrite to replacement by chalcocite is strikingly illustrated by relations to be noted in specimens of poryphry ore from the Ely mines. Detailed examination of polished surfaces and of thin slices shows that as a rule most of the secondary chalcocite has formed on chalcopyrite. In certain specimens containing no visible chalcopyrite the pyrite has been deeply changed to chalcocite, but where both of the primary sulphides are present and where the chalcopyrite grains are deeply coated with chalcocite, the neighboring grains of pyrite are either covered by very thin films or have not been coated at all. Similar relations of sensitiveness to chemical attack are exhibited under the following experimental conditions: If fragments of chalcopyrite and of pyrite are touched simultaneously by pieces of iron while immersed in a solution of cupric sulphate, a very noteworthy effect is immediately apparent on the surface of the chalcopyrite but the pyrite at first seems to be inert. It is possible by this procedure to form on chalcopyrite a brilliant blue coating, presumably covellite, and to withdraw the iron pieces while the pyrite is still bright and fresh.

From the volume relations which have been indicated and the

[1] In these calculations the figures used for specific weight are: pyrite, 4.83–5.2; chalcopyrite, 4.1–4.2; chalcocite, 5.5–5.8.

observed scanty replacement of pyrite by chalcocite in the porphyry ores, the writer is inclined to the belief that in general the replacement of pyrite by chalcocite does not take place unless the active solution contains, in addition to cupric sulphate, some other substance capable of attacking either the pyrite or the chalcocite. Many observations indicate that metasomatic replacement of one mineral by another usually takes place in such a way that the new mineral occupies the same space as the old mineral. This relation has been convincingly set forth by Lindgren,[1] and by Bastin.[2] With reference to secondary chalcocite, Ransome[3] makes the following statement:

> "In the Miami-Inspiration ore bodies of the Globe district, many of the specks of chalcocite are solidly embedded in the silicified schist and in veinlets of quartz, so that they have the appearance of being products of the earliest period of mineralization. Yet the evidence here is conclusive that these specks of chalcocite have resulted from the alteration of pyrite and chalcopyrite, and probably in most cases exactly fill the space once occupied by the present mineral. All stages may be seen from pyrite thinly coated with chalcocite to solid chalcocite."

If the relation of equal volume holds as it is believed to hold in the replacement of pyrite by chalcocite it is obvious that not all the changes involved are summarized by the Stokes equation. In replacement by equal volume the product contains less chalcocite than would correspond molecularly with the pyrite that has been destroyed, and it seems that the removal of the excess material must be accounted for as a result of the attack of some reagent other than cupric sulphate. It is possible that chalcocite replacement of pyrite is promoted by the presence of a minor concentration of ferric sulphate in the active solution. It is difficult to obtain a visible deposit of copper sulphide on pyrite or chalcopyrite by treatment with a solution of cupric sulphate

[1] Lindgren, W., "The Nature of Replacement," ECON. GEOL., Vol. 7, pp. 521–535, 1912.

[2] Bastin, E. S., "Metasomatism in Sulphide Enrichment," ECON. GEOL., Vol. 8, pp. 51–63, 1913.

[3] Ransome, F. L., "Criteria of Downward Sulphide Enrichment," ECON. GEOL., Vol. 5, p. 218, 1910.

alone, yet blue coatings may be readily formed on either mineral if ferrous sulphate is added. This fact may have a direct bearing on the problem under consideration. The reaction is accelerated by heating, but it takes place within a few hours at ordinary temperature. During the progress of the reaction insoluble iron compounds are precipitated and after sulphide deposition has taken place the solution responds to the test for ferric iron with potassium sulphocyanide. As already noted (p. 640) ferric sulphate is formed by the interaction of ferrous and cupric sulphates in solution, so that obviously secondary covellite and chalcocite are both formed in the presence of at least minute concentrations of ferric sulphate.

COMPOSITION OF MINE WATER.

Chemical analyses of samples of water from the Ruth and Brooks porphyry mines are given in the subjoined table:

Composition of Waters from Porphyry Mines.

(Parts per million.)

	I.	II.
Na	35	33
K	11	27.6
Ca	126	105.7
Mg	trace	26.3
Fe″	19	36.4
Fe‴	none	42.0
SO_4	256	556.0
Cl	8.5	55.4
CO_3	38[1]	
HCO_3	117[1]	
SiO_2	28	94.0
Total	638.5	976.4
Reaction	alkaline	not stated

I. Water from Brooks inclined shaft of the Giroux Consolidated Company collected in September, 1910. The preceding summer had been dry and the water stood about 230 feet below

[1] Total CO_3 distributed between CO_3 and HCO_3 in proportions to balance the reacting values of bases and acids. As reported, the analysis shows HCO_3 156 parts per million.

the surface. A test was made for copper with negative result. Analysis made in the laboratory of the Geological Survey by Dr. Chase Palmer. Ferrous iron was determined immediately after taking the sample to be 22 parts per million so that the iron was all in the ferrous state. For this determination the writer is indebted to Mr. A. J. Sale.

II. Water from Ruth mine. Composition calculated to parts per million of ions, from analysis by Dr. Harry East Miller, recorded by A. C. Lawson.[1]

The analysis of the Ruth mine water was originally stated in the following form:

Analysis of Ruth Mine Water Grains per Gallon of 231 Cu. In.

SiO_2 + insoluble matter	5.50
NaCl	4.88
KCl	.55
K_2SO_4	2.96
$FeSO_4$	3.77
$Fe_2(SO_4)_3$	8.78
$CaSO_4$	20.99
$MgSO_4$	7.61
Organic matter and water of sulphates	6.96
Total	64.00

In regard to this analysis Professor Lawson[1] says:

"It is probable that the proportion of ferric sulphate is higher than is actually the case in the mine, owing to the difficulty of preventing oxidation of the ferrous salt. The result is interesting as an indication of the materials which are being leached from the porphyry by the descending meteoric waters. Another sample of the mine water analyzed in the mine laboratory as expeditiously as possible after collection, by Mr. Herbert Ross, gave results from which it would appear that the iron of the mine water is nearly all in the ferrous state."

The form in which the Ruth analysis is stated does not enable classification of the water, but the Brooks analysis indicates the following characteristics:[2]

[1] Lawson, A. C., "The Copper Deposits of the Robinson Mining District, Nevada," Pub. Bull. Univ. of Cal., Dept. of Geology, Vol. 4, p. 332, 1906.

[2] Palmer, Chase, "The Geochemical Interpretation of Water Analysis," Bull. U. S. Geol. Survey No. 475, p. 13, 1911.

	Per cent.
Primary salinity	20.6
Secondary salinity	42.8
Primary alkalinity	00.0
Secondary alkalinity	29.0
Sub alkalinity	7.6
	100.0

It should be noted that the mine waters that have been analyzed are in a way the complement of the pyrite porphyry for they contain in solution the bases which are known to have been leached out of the rock during the processes of enrichment and of ore decomposition. The high proportion of lime in both of the mine waters indicates that the mines have received contributions of water through percolation from the limestone masses which adjoin the ore masses, because the porphyry ores are essentially free from lime. The indicated absence of magnesium in the Brooks mine water appears to be anomalous for the analyses of samples indicate that the ore porphyry of the district carries more of this element than it does of lime.

The alkaline reaction of the Brooks mine water bears out the suggestion that has been made on another page that the waters from which chalcocite has been deposited were probably not strongly acid.

CHEMICAL CHARACTER OF SOLUTIONS WHICH DEPOSIT CHALCOCITE.

Among the products of the oxidation of pyrite is sulphuric acid so that the solutions which carry copper from the places of decomposition to those of chalcocite deposition must be distinctly acid when they are first formed, and it is well known that waters collected from the upper levels of mines in pyritic ore bodies usually show an acid reaction. However, carbonate and many silicate gangue minerals are decomposed by acids and when such minerals are long in contact with the descending solutions their bases are taken into combination and the original acidity of the solution gradually disappears. Attention has been recently directed to the fact that the waters in certain copper mines are

less and less acid at lower and lower levels,[1] and are alkaline in some of the deepest workings, and there can be little doubt that this state of affairs is general. A sample of water collected from a point near the top of the water table in one of the Ely porphyry mines was found to be distinctly alkaline (see p. 644). Although these observations have led to the suggestion that a reduction of acidity in descending metalliferous solutions may be important in connection with secondary sulphide deposition[2] it is not obvious, merely because solutions in a given case have become alkaline as a result of reaction with gangue minerals, that the conclusion must follow that no part of the dissolved copper could have been deposited before the alkaline state had been reached. The opposite contention that acidity may be necessary for the progress of copper sulphide enrichment is suggested by Welsh[3] and Stewart who found by experiment that, while chalcopyrite may be coated with films resembling bornite by treatment with cupric sulphate solution, the presence of calcite prevents the reaction. These writers state that,

"The ordinary copper sulphate is acid and the effect of the calcite may be to neutralize this acidity."

The present writer has observed that artificial coatings may be readily formed on chalcopyrite in solutions possessing only the slight acidity due to the presence of cupric and ferrous sulphates, but that when a little sulphuric acid is added the mineral remains untarnished. Also Winchell[4] states that, while he obtained chalcocite in the presence of SO_2, without this reducing agent pyrite was not visibly attacked by acidified cupric sulphate at the end of two years.

From the foregoing observations it appears likely that under natural conditions chalcocite will not replace primary sulphides

[1] Emmons, W. H., "The Enrichment of Sulphide Ores," Bull. U. S. Geol. Survey No. 529, pp. 60 and 89, 1913.

[2] Wells, R. C., discussion of a paper by F. L. Ransome, on "The Criteria of Downward Enrichment," Econ. Geol., Vol. 5, p. 482, 1910; Emmons, W. H., *loc. cit.*, p. 60.

[3] Welsh, T. W. B., and Stewart, C. A., "Note on the Effect of Calcite Gangue on the Secondary Enrichment of Copper Veins," Econ. Geol., Vol. 7, pp. 785–787, 1912.

[4] *Op. cit.*, p. 274.

when the acidity of the cupriferous solutions exceeds some rather small minimum, but that an alkaline condition is not necessary in order that the reaction may proceed.

CHALCOCITE DEPOSITION IN THE PRESENCE OF CALCITE.

At several places in the Ely district chalcocite has been noted in the form of secondary coatings on pyrite and chalcopyrite disseminated through masses of partly weathered metamorphosed limestone lying beneath a surficial shell of fully oxidized material. Considerable bodies of enriched material in altered limestone masses have been developed in the Old Glory mine where the original matrix of the primary sulphides, though consisting largely of lime silicate minerals, also comprises considerable calcite. In material of this sort the deposition of chalcocite would appear to be uncommon according to D. C. Bard[1] who states, as a result of his observations, that sulphide enrichment is usually lacking where the gangue comprises much calcite. The explanation offered is that copper sulphate reacts with calcite to form copper carbonate, so that only an excess of the copper salt above that required for replacement of calcite can finally appear as covellite or chalcocite.

Welsh and Stewart[2] treated chalcopyrite in the presence of calcite, and also chalcopyrite mixed with quartz, with moving solutions of cupric sulphate in upright tubes so arranged that the lower part of the column was continually flooded. These writers state that,

> "In the calcite chalcopyrite mixture the calcite above the water level was distinctly tinged with green, while none of the chalcopyrite showed any change. In the tube containing quartz and chalcopyrite no change above the water level was noted, but the chalcopyrite for four inches below this level showed clearly the purple tinge of bornite, and upon closer examination some thin black films were found."

In this experiment the solution draining from the calcite-chalcopyrite mixture still contained cupric sulphate, and the authors suggest that secondary sulphide was not precipitated be-

[1] Bard, D. C., "Absence of Secondary Copper-sulphide Enrichment in Calcite Gangue," ECON. GEOL., Vol. 5, pp. 59–61, 1910.

[2] *Op. cit.*

cause the solution may have been rendered alkaline through reaction with the calcite. Whether the explanation offered is the true one or not, on its face the experiment bears out the suggestion presented by Bard that the presence of calcite is unfavorable for the deposition of secondary copper sulphides. However, the present writer has found that calcite does not precipitate copper from a solution containing both cupric and ferrous sulphates, and, furthermore, that by means of such a solution pyrite and chalcopyrite may be readily coated with secondary sulphide films in the presence of large amounts of calcite.

Because specimens of the chalcocite-bearing ore from the Old Glory mine now contain no calcite, the possibility remains that here the secondary sulphide was not actually deposited in the presence of calcite but only in material from which calcite had previously been removed as the result of solution by sulphuric acid. Observations more detailed than those that have been made would be required to determine whether the last of the original calcite disappeared before or after chalcocite enrichment occurred.

WATER TABLE RELATIONS DURING CHALCOCITE DEPOSITION.

The position of standing water in the porphyry mines of the Ely district varies from time to time. No systematic record of rise and fall is at hand, but in the autumn of 1910 the water in some of the mines was about 30 feet higher than in the autumn of 1909. In general the chalcocite porphyry, though lying mainly above the water table, continues downward below the highest position of standing water, and possibly below the levels to which the water top may sink at the lowest stage. It seems probable, however, that no porphyry containing so much as 0.5 per cent. of secondary copper occurs at lower levels than those where the top of ground water may have stood during the dry epochs of the Quaternary period. Before the first expansion of the Great Basin lakes and in the interval between the two expansions the climate was probably somewhat drier than it has been during the present epoch, and the mean position of standing water may have been for considerable periods from 50 to 100 feet lower than it is now. In the Alpha mine, where the ore bodies are not of the disseminated

type but are rather of the nature of compact segregations, the water table is now fully 200 feet higher than it has been formerly. Here oxidation has penetrated more than 1,200 feet below the surface, while the natural level of standing water is at a depth of about 1,020 feet. On the other hand, during those epochs when the Great Basin lakes were in flood stage, in the porphyry ore masses the water level certainly stood much above its present mean position. Deposits of iron-copper sinter that occur near some of the mines furnish good evidence that the chalcocite ore was once at least submerged to a height so great that part of the products of its oxidation escaped into the surface drainage. This event is correlated on physiographic evidence with the first Quaternary humid epoch, when rather steady streams were undoubtedly flowing in the district, and as the next later humid epoch seems to have been wetter than the first, the ore bodies may have been submerged a second time. If the later flood stage of the groundwater was higher than the earlier, the top of the ore body would have been below water level, a supposition which would adequately account for the lack of sinter deposits in the swales which were eroded during the second humid epoch. Presumably similar alternations of low and high water were characteristic of late Pliocene time when the principal segregation of chalcocite is believed to have occurred.

It would seem that a considerable body of sulphides lying above the water table would offer the best possible conditions for the retention of copper taken into solution by oxidizing surface waters. This suggestion is based in part upon the conception that the speed of reaction between copper solutions and primary sulphides is slow under the most favorable conditions, and presumably extremely slow after grains of pyrite and chalcopyrite have received moderately deep films of chalcocite. A long journey involving contact with a very large number of primary sulphide grains would be more favorable to precipitation of a larger proportion of the dissolved copper than a short journey during which correspondingly few grains would be encountered by any unit volume of solution. A low water table and a high position of the ore top would tend to produce a thick ore body of rather

uniform grade from near its top to somewhere near its bottom. So long as the solutions could be exhausted above standing water, the enriched material would grade imperceptibly into the primary material. On the other hand, if copper were not exhausted above standing water, precipitation should continue within a relatively thin shell of material just below the water table, because the solutions in this situation would necessarily move laterally rather than downward, and their flow or passage would be at a diminished rate, permitting much longer contact with reacting primary sulphides in a limited mass of material. During such times as the groundwater may have stood well up in material previously enriched, the tendency would have been to produce layers of ore carrying more than the average amount of copper. What is possibly the record of a former high stage of groundwater is seen in the local occurrence of particularly rich layers of ore beneath from 20 to 50 feet of medium-grade material lying just under the oxidized capping.

DATES OF CHALCOCITE ENRICHMENT.

In foregoing sections which deal with the chemistry of chalcocite enrichment, the idea has been developed that the porphyry ore bodies of the Ely district are currently subject to wastage in their upper portions, and to accretion of copper in their lower portions. A similar downward transfer of copper has undoubtedly been going on in the past, and it is obvious that the present ore bodies are the successors of similar segregations which formerly existed above the places where the enriched material is now found. The rocks along the metamorphosed zone were undoubtedly charged with pyrite and chalcopyrite for several hundred, and perhaps for several thousand, feet above the present surface, and the earliest formation of disseminated chalcocite ores may be thought of as having occurred when, as a result of erosion, the masses of pyritized rock first came under the action of oxidizing solutions. This conception would carry the operations of chalcocite enrichment a long way back into the past.

It is held that the volcanic rocks, of probable Pliocene age, which now occur from place to place within the district formerly

extended over much wider areas, and probably covered all of the ore belt. But the pyritized rocks had been undergoing erosion for a long time before the period of volcanic extravasation and there can be no reasonable doubt that the processes of chalcocite enrichment had been going on hand in hand with the gradual lowering of the land surface. However, it is not safe to conclude that ore bodies comparable with those of the present existed at any particular time, and it is not possible to state whether or not thick masses of disseminated chalcocite ore existed when the rhyolite lavas flowed out upon the old land surface.

The processes of weathering and chalcocite deposition must have been in abeyance during a long period devoted to the erosion of the rhyolite, but when the rocks of the metamorphosed zone had been partially stripped these processes again came into play and have since been operative except for such interruptions as resulted when the ore bodies may have been overtopped by groundwater.

On physiographic grounds it seems certain that there has been practically no erosion of the ground above the ore bodies since the beginning of the pre-Bouneville epoch (the first division of Quaternary time) during which great alluvial cones were built up throughout the region about the mouths of lateral canyons that open out into the broad north-south valleys. All of the secondary copper contained in the present ore bodies had therefore been segregated below the now existing surface before the close of the Pliocene, and the fact that thick masses of enriched material exist is due to conditions during the latter part of Pliocene time that were prevailingly favorable for the precipitation and accumulation of copper in the form of chalcocite.

While essentially all of the secondary or added copper now present in the disseminated ore bodies had been brought together before the beginning of Quaternary time, it seems almost necessary to believe that redistribution of the metal has since been going on with the result that the tops of the ore bodies have been gradually falling to lower and lower positions. No basis has been found, however, for determining what portion of the depth of oxidized capping is attributable to Quaternary decomposition.

A COMPARISON OF WATERS OF MINES AND OF HOT SPRINGS.

W. H. Emmons and G. L. Harrington.[1]

INTRODUCTION AND SUMMARY.

The theory that most of the lode ores of copper, silver, and gold have been deposited by ascending hot waters and that many of them have been subsequently enriched by descending cold waters is almost universally accepted. There is not, however, universal accord concerning the source of the solutions that have deposited the primary ores of these metals, although the trend of geological opinion in late years is in the main toward a belief in the agency of magmatic waters. Many field geologists, nevertheless, still utilize at least three working hypotheses in the investigation of a group of mineral deposits: one, that the ores have been formed by ascending magmatic solutions; another, that they have been deposited by ascending hot meteoric waters; and still another, that they have been deposited by cold waters. By the utilization of these hypotheses with appropriate groups of criteria, the genesis of some deposits of lode ores has been proven almost beyond reasonable doubt. Many of the larger problems connected with the genesis of these ores are, however, only in process of solution, and conclusive statements must await a more adequate knowledge of the chemical, physical, and geological processes involved in their deposition.

The present investigation was undertaken particularly with a view of ascertaining the general nature and composition of the waters that have been assumed to be agents in the deposition of lode ores, in order that chemical experiments designed to illustrate the natural processes might be accomplished, as far as practicable, under natural conditions. Although this investiga-

[1] Published by permission of the Director of the United States Geological Survey.

tion is not yet completed, it seems desirable to publish the principal results of the inquiry at this time in order that they may be available to other investigators who are engaged in experimental work.

Seventy-five analyses of hot springs and forty-two analyses of mine waters have been tabulated, and when necessary, reduced to parts per million and to uniform statements so that they may more readily be compared. The analyses of hot springs have been divided into two groups, one representing the springs that issue from regions of late volcanic activity, and one representing

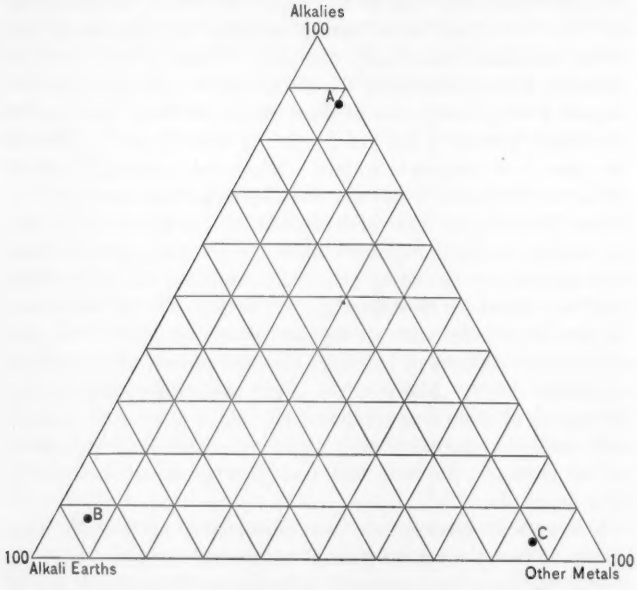


FIG. 54. Diagram showing relative proportions (reacting values) of alkalies, alkali earths, and other metals, in *A*, an average of 58 analyses of hot springs from areas of relatively late volcanic activity; *B*, an average of 17 analyses of hot springs from areas of remote volcanic activity; and *C*, an average of 42 mine waters. Metal radicals in water: *A*, hot springs near igneous rocks; *B*, hot springs in sedimentary or old igneous rocks; *C*, mine waters.

the springs that issue from regions of more remote volcanic activity.

A comparison of the averages of the results obtained shows that the waters of the three groups carry essentially the same elements, although there are great differences in the amounts of the elements that are carried. These differences are shown graphically by the triangular diagrams figured below. As shown by Fig. 54, the ascending hot waters in areas of relatively late volcanic activity (*A*) are essentially solutions of the alkalies, although they carry also alkaline earths and other metals. The hot waters in areas of more remote volcanic activity (*B*) are

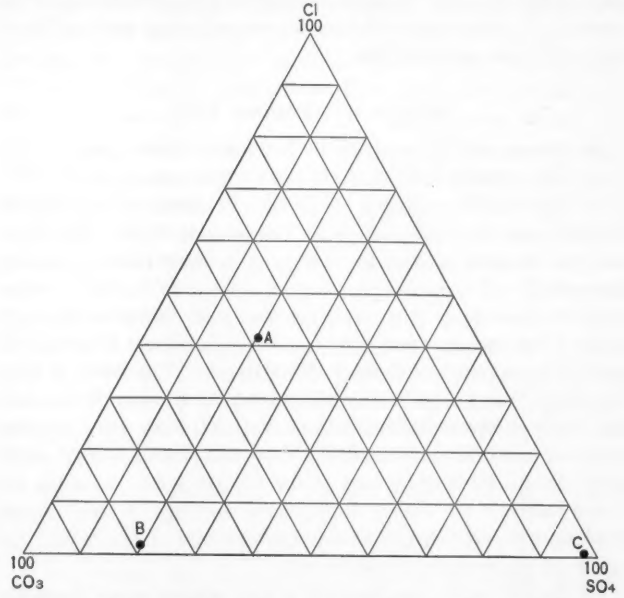


FIG. 55. Diagram showing relative proportions (reacting values) of Cl, CO_3, and SO_4, in *A*, an average of 58 analyses of hot springs from areas of relatively late volcanic activity; *B*, an average of 17 analyses of hot springs in areas of remote volcanic activity; and *C*, an average of 42 mine waters. Acid radicals in waters: *A*, hot springs near igneous rocks; *B*, hot springs in sedimentary or old igneous rocks; *C*, mine waters.

essentially alkaline earth solutions, although they carry some alkalies and other metals. Mine waters (*C*) are chiefly solutions of the heavy metals with appreciable amounts of alkaline earths and some alkalies.

The negative radicles except group *A* likewise are grouped in the three corners of the triangular diagram as is indicated by Fig. 55. In the hot waters of regions of late volcanic activity (*A*), chlorides predominate, although there is but a slightly lower proportion of carbonates and there is also an appreciable proportion of sulphates. Hot waters from areas of remote volcanic activity (*B*) are essentially carbonate solutions, although they contain also sulphates and chloride in appreciable quantities. Mine waters (*C*) are chiefly sulphate waters and carry only a little of the carbonates and chlorides.

SOURCES OF ANALYSES USED.

In the selection of analyses of hot waters from areas of relatively late volcanic activity (series *A*), effort was made to secure them from widely separated localities. Seventeen of the analyses however are from the geysers of Yellowstone Park. This number was included because the waters show great diversity among themselves and because the analyses appear to be more nearly complete than many others that are available. Some of the analyses of hot springs from regions of comparatively late volcanic activity were obtained from F. W. Clarke's "The Data of Geochemistry,"[1] and from earlier bulletins by Dr. Clarke. The seventeen analyses from the Yellowstone National Park were reported by Gooch and Whitfield[2] in 1888. Many analyses are from Peale's[3] paper on the Mineral Springs of the United States, in which are stated analyses of waters from many sources. A few of the analyses were taken from advertising literature of resorts and the names of the analysts are not stated.

Of the fifty-eight analyses, six are of waters from Montana;

[1] Bull. U. S. Geol. Survey No. 491.

[2] Bull. 47 U. S. Geol. Survey, "Analyses of Waters of Yellowstone National Park, 1888."

[3] Bull. U. S. Geol. Survey No. 32, 1886.

seventeen from the Yellowstone National Park; ten from Colorado; eleven from California; two are from Nevada; four are from New Mexico; one each from Idaho, Utah, Oregon, and Arizona. Of foreign waters, one is from New Zealand, one from Carlsbad, Bohemia, and two are from Colombia.

To obtain the average the analyses were recalculated where necessary and expressed in a similar form and their sum was divided by fifty-eight, the number of analyses. The final average may be considered to represent an analysis of a composite sample obtained by mixing equal amounts of the various waters.

A different method was employed in averaging the seventeen analyses from regions of remote volcanic activity (series *B*). Ten of these waters are from Hot Springs, Ark.,[1] one from Georgia Hot Springs,[2] and six are from Virginia Hot Springs.[3] The ten analyses of waters from Hot Springs were averaged; those of waters from Virginia Hot Springs were already expressed as a composite of six analyses. These two averages were added to the analysis of the water from Georgia and the average of the three is expressed as parts per million.

Of the forty-two analyses of mine waters, thirty-seven are stated in Bulletin 529, U. S. G. S.,[4] three are analyses of mine waters from Waihi, N. Z.,[5] and two are from the Homestake mine,[6] South Dakota.

Owing to the fact that some of the ions are grouped in a few of the analyses, it was necessary to make some approximations. For example, a few of the analyses gave $MgCO_3$ and $CaCO_3$ together, a few gave Fe_2O_3 and Al_2O_3 together and some of the mine waters gave K_2O and Na_2O together. These approxima-

[1] Weed, W. H., "Hot Springs of Southern United States," Water Supply Paper 145, U. S. Geol. Survey, p. 202.

[2] Weed, W. H., "Warm Springs of Georgia," H. C. White, analyst, Water Supply Paper U. S. Geol. Survey No. 145, p. 186.

[3] "The Virginia Hot Springs," a composite of six analyses by F. W. Clarke, Bull. U. S. Geol. Survey No. 9, 1884, p. 33.

[4] Emmons, W. H., "The Enrichment of Sulphide Ores," Bull. 529 U. S. Geol. Survey, 1913, pp. 60–64.

[5] Bell and Frazer, Bull. New Zealand Geol. Survey No. 15, 1913, p. 69.

[6] Sharwood, W. J., ECON. GEOLOGY, Vol. VI., p. 742.

tions make up so small a part of the total that the errors introduced are not large.

If the various analyses of waters that were used to obtain the averages platted on Figs. 54 and 55 are platted separately on the triangular diagrams, the latter will show the segregation of the six groups of ions towards the corners of the diagrams, but the segregation of the groups of ions is not so conspicuous. This method will bring out some details that are not indicated on Figs. 1 and 2, but by its use equal weights are given to waters having low concentration and to waters having high concentration. If equal weight is given to each analysis regardless of concentration, the average of hot spring waters from regions of comparatively late volcanic activity will show nearly equal amounts of the negative radicles Cl, CO_3 and SO_4. On the other hand, the average of analyses of hot waters from areas of more remote volcanic activity and the average of analyses of mine waters will show differences that are less noteworthy. If a larger number of analyses had been included different averages would have been obtained, but it is believed that the general results would be closely similar. Series *B*, which represents only seventeen analyses from only three regions, is perhaps questionably representative. The analyses that were used to obtain this average are of waters that belong to the same general class, however, and so far as the proportions of the more important radicles are concerned they show little variation.

STATEMENTS OF RESULTS.

In the table given on page 660 are stated the averages of the three groups of analyses. Columns 1, 2, and 3 are averages in parts per million from which percentages of ions of columns 4, 5, and 6 were computed. Columns 7, 8, and 9 represent the "reacting values"[1] of the different ions. If the atomic weight or radicle weight be divided by the valence of the element or radicle, and the number of parts per million be divided by this quotient, the result is the reacting value.

[1] Palmer, Chase, "The Geochemical Interpretation of Water Analyses," Bull. 479 U. S. Geol. Survey, 1911.

In columns 10, 11, and 12 the reacting values are grouped. One group includes Cl, Br, I and F; another includes PO_4, B_4O_7, AsO_4, NO_3, and S. The metals are grouped as alkalies, alkaline earths, and other metals. In columns 13, 14, and 15 are given the percentages on the basis of reacting values of each of the principal negative ions and of the three metallic groups. These percentages were used in the construction of the triangular diagrams, Figs. 54 and 55.

It is to be noted that in any analysis the sum of the reacting values of the negative radicles should equal the sum of the reacting values of the positive radicles, but in each of these series of analyses the sum of the reacting values of the positive radicles (including hydrogen) is greater than that of the negative radicles. In series *A* this may be due partly to the fact that silica acts as an acid. Moreover, some of the alumina and ferric oxide in all three series may occur in the colloidal state uncombined with any acid radicle, and so should not be given a reacting value. The difference in each series is less, however, than the sum of the reacting values of Fe and Al as given in columns 7, 8, and 9. This suggests the presence either of hydroxides, carbonates or of bicarbonates not accounted for.

The chemical character of the averages of the three series of analyses is indicated in the table below. In the table the ions are grouped according to the classification recently described by Palmer.[1] Both averages of hot spring waters are alkaline while the average mine water is acid. This statement, however, does not apply to all mine waters, but only to those in the upper zones of ore deposits. In depth mine waters also doubtless become alkaline.[2]

WATERS OF HOT SPRINGS IN REGIONS OF LATE VOLCANIC ACTIVITY (SERIES *A*).

The composition of most hot spring waters, as stated in the analyses, is simple. Usually there are not more than five or six

[1] Palmer, Chase, "The Geochemical Interpretation of Water Analyses," Bull. U. S. Geol. Survey No. 479, 1911, p. 13.

[2] Emmons, W. H., "The Enrichment of Sulphide Ores," Bull. U. S. Geol. Survey No. 529, 1913, p. 89.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	A	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
Cl	797.07	2.10	39.30	22.97	.68	.40	22.48	.059	1.11						
Br	.25	tr.	tr.	.01	tr.		.003	—	—	22.49	.059	1.11	41.2	1.1	.7
I	.22	tr.	—	.01	tr.		.002	—	—						
F	.12	—	tr.	tr.	—		.006	—	—						
SO_4	536.35	49.75	7,551.99	15.45	16.15	75.89	11.17	1.034	157.23	11.17	1.034	157.23	20.4	19.8	97.6
CO_3	628.70	124.04	83.01	18.12	40.27	.83	20.96	4.135	2.77	20.96	4.135	2.77	38.4	79.1	1.7
										54.62	5.228	161.11	100.0	100.0	100.0[1]
PO_4	.03	—	tr.	tr.	—	tr.	.001	—	—						
AsO_4	.65	—	tr.	.02	—	tr.	.007	—	—						
B_4O_7	122.83	.05	tr.	3.54	.02	tr.	1.57	.0006	—						
NO_3	—	.11	tr.	—	.04	tr.	—	.0018	—	2.50	.002	—			
S	14.78	—	.02	.43	—	tr.	.92	—	—						
As	.05	—	—	tr.	—	—	—	—	—						
Sb	.01	—	—	tr.	—	—	—	—	—						
Na	1,037.38	6.65	63.28	29.89	2.16	.64	45.10	.289	2.75						
K	49.12	4.97	30.32	1.41	1.61	.31	1.26	.127	.78	48.15	.416	3.53	87.4	7.6	3.4
Li	1.55	tr.	—	.04	tr.		.22	—							
NH_4	28.31	.02	—	.82	.01		1.57	—							
Ca	71.80	74.08	161.01	2.07	24.05	1.62	3.58	3.697	8.05						
Sr	.03	—	—	tr.	—		—	—		5.64	4.744	22.12	10.3	86.6	21.2
Ba	.03	—	—	tr.	—		—	—							
Mg	25.10	12.74	171.16	.72	4.14	1.72	2.06	1.047	14.07						
Mn	.01	.08	40.76	tr.	.03	.41	—	.003	1.48						
Fe	3.88	.26	239.70	.11	.08	2.41	.14	.093	10.99[2]						
Al	10.01	2.03	253.97	.29	.66	2.55	1.11	.225	28.09	1.25	.321	78.36	2.3	5.8	75.4
Co, Cd, Ni, Pb	—	—	1.22	—	—	.01	—	—	.02						
Cu	—	—	1,147.69	—	—	11.53	—	—	36.15						
Zn	—	—	53.14	—	—	.53	—	—	1.63						
										55.04	5.481	104.01	100.0	100.0	100.0[3]
SiO_2	129.07	31.12	53.07	3.72	10.10	.53	4.28	1.032	1.76	4.54	1.032	1.76			
SiO_3	9.58	—	—	.29	—	—	.26	—							
H	3.14	—	61.31	.09	—	.62	3.12	—	60.82	3.12		60.82			
Totals	3,470.47	308.00	9,950.93	100.00	100.00	100.0									

[1] Sums of halogens SO_4 and CO_3.

[2] 56 per cent. F‴, 44 per cent. Fe″.

[3] Sums of metals.

	Reacting Values.			Percentages.		
	Hot Springs *A.*	Hot Springs *B.*	Mine Waters.	Hot Springs *A.*	Hot Springs *B.*	Mine Waters.
Alkalies	48.15	.416	3.53	—	—	—
Alkali earths and other metals	6.89	5.065	100.48	—	—	—
Hydrogen	3.12	—	60.82	—	—	—
Strong acids	35.24	1.095	158.19	—	—	—
Weak acids	21.98	4.135	2.77	—	—	—
Primary salinity	70.48	.832	7.06	64.0	7.6	2.2
Secondary salinity	—	1.358	200.96	—	12.4	63.5
Tertiary salinity	—	—	108.36	—	—	34.3
Primary alkalinity	25.82	—	—	23.5	—	—
Secondary alkalinity	13.78	8.772	—	12.5	80.0	—
	110.08	10.962	316.38	100.0	100.0	100.0
Alkalinity	39.6	8.77	—			
Acidity	—	—	108.36			

1. Series *A*. Average of 58 analyses of hot springs in areas of comparatively late volcanic activity. Results are expressed as parts per million.

2. Series *B*. Average of 17 analyses of hot springs in areas of comparatively remote volcanic activity. Results are expressed as parts per million.

3. Series *C*. Average of 42 analyses of mine waters. Results are expressed as parts per million.

4. Series *A*. Average of 58 analyses of hot springs in areas of comparatively late volcanic activity. Results are expressed as percentages of dissolved material.

5. Series *B*. Average of 17 analyses of hot springs in areas of comparatively remote volcanic activity. Results are expressed as percentages of dissolved material.

6. Series *C*. Average of 42 analyses of mine waters. Results are expressed as percentages of dissolved material.

7. Series *A*. Average of 58 analyses of hot springs in areas of comparatively late volcanic activity. Results are obtained by dividing weight of ion by its valence and parts per million by the quotient.

8. Series *B*. Average of 17 analyses of hot springs in areas of comparatively remote volcanic activity. Results are obtained by dividing weight of ion by its valence and parts per million by the quotient.

9. Series *C*. Average of 42 analyses of mine waters. Results are obtained by dividing weight of ion by its valence and parts per million by the quotient.

10, 11, 12. Reacting values of columns 7, 8, 9, in appropriate chemical groups.

13, 14, 15. The chemical groups obtained by expressing analyses (columns 1, 2, 3) according to their reacting values are reduced to percentages of alkalies, alkali earth, and other metals, and to percentages of chlorides (and other halogens), sulphates, and carbonates.

compounds present in any great amount, but there will generally be found also very small amounts of at least as many more. In the more recent analyses more elements are indicated than in those of earlier date. In these, either the amount in parts per million is given or the statement is made that traces have been determined by spectroscopic methods.

In the analyses that have been collected, there are but two waters of series *A* which have over 10,000 parts dissolved material per million. These waters greatly influence the average, since they contain more than half of the total chlorine, about one fourth of the sulphate radicle, and about 48 per cent. of the CO_3 of the 58 analyses. If these waters had not been included, the proportion of SO_4 in the average would be greater. Omitting these, the averages obtained are Cl, 22.97 per cent.; CO_3, 18.12 per cent.; SO_4, 15.45 per cent. Thus the order of the three ions is the same in both averages. Chlorine was absent in one analysis, SO_4 was absent in one, and a trace only was present in another, while CO_3 was not found in thirteen analyses. Free CO_2 was found in several analyses but does not appear in the final average because some of the original analyses are in such form that the amount cannot be computed. In some instances the statement was made that free CO_2 was present but the amount was not stated. All bicarbonates were recalculated to normal carbonates for the sake of uniformity. Free hydrochloric and free sulphuric acid appear in four analyses, as do free acids of arsenic and boron. Arsenic and boron are stated in various forms in the original analyses, but for the sake of uniformity were reduced to the acid radicles AsO_4 and B_4O_7. Boron appears in 27 of the 58 analyses. The average percentage of B_4O_7, 3.54 per cent., is noteworthy. This high average is in part accounted for by the fact that there are included six analyses showing from 9 per cent. to 40 per cent., and 16 analyses from the Yellowstone Park, each containing 7 per cent. to 3 per cent. B_4O_7. Only the analyses of waters from the Yellowstone Park show AsO_4. Possibly a considerable proportion of the arsenic should be regarded as the sulphide. This element, presumably in the form of the sulphide, is found

at Sulphur Bank, California, and Ojo Caliente, New Mexico. Silica appears in the analyses as SiO_2, as sodium silicate, Na_2SiO_3 and as "colloidal silica" which was calculated as SiO_2. SiO_2 equals 3.72 per cent. and SiO_3 equals .29 per cent.

Other acid radicles appearing in the analyses are PO_4, Br, I, and F, all being present in amounts below .01 per cent.

Sulphur constitutes about .43 per cent. of the dissolved salts. It is present mainly as hydrogen sulphide, but four analyses show calcium and sodium sulphides. Three of these state the total amounts of the two alkalies but do not state the amount of each alkali present. The percentage of sulphur is probably too low, since in the discussions of some of the analyses it is stated that the water "had the odor of H_2S," or "H_2S also present," or "some sulphur in suspension," the amount of sulphur not being stated. If it is assumed that the sulphate ion is the oxidation product of sulphide then the total sulphide ion before oxidation equaled 6.2 per cent.

Many metals are present in this average of hot waters. Sodium is the most common, 29.89 per cent., followed by calcium, 2.07 per cent., potassium 1.41 per cent., magnesium .72 per cent., while iron and aluminum together amount to only .40 per cent. The average analysis shows .04 per cent. of lithium. Manganese, strontium, and barium are present in comparatively few analyses, and in these in but small amounts, averaging only a trace. Traces of rubidium and of cæsium are found in one analysis, and traces of mercury in another. Two analyses included in the average contain over 54 per cent. of the sodium of the total of the average water. They contain also a little less than 42 per cent. of the potassium, about 4 per cent. of the magnesium, and 8 per cent. of the calcium. It is thus evident that if these two analyses were rejected, the ratio of alkalies to alkaline earths would be somewhat lower. While sodium was present in all of the analyses and in one constituted 49.2 per cent. of the total salts, potassium was present in but forty-seven out of the fifty-eight, of which eight show traces only. The largest amount is about 11 per cent., in a hot water from Wagon Wheel Gap.

The elements indicated in this average are for the most part the

commoner constituents of the earth's crust, although arsenic, antimony, boron, bromine, cæsium, iodine, lithium, mercury and rubidium are present in subordinate amounts.

In connection with current theories of the deposition of lode ores it is noteworthy that in these fifty-eight analyses no traces are reported of zinc, titanium, tungsten, lead, nickel, molybdenum, copper, cadmium, cobalt, bismuth, gold, or silver, nor is there any indication of tellurium.

Another interesting fact to be noted in connection with these thermal spring waters is the high sodium-potassium ratio, about 21. This is notably higher than that of the other two series of analyses. It is noteworthy that this ratio approaches that of these two elements in sea water, which varies from 26 to 35, with one exceptional analysis showing the ratio to be as low as 15. The waters of all closed basins show likewise a high ratio.[1]

WATERS OF HOT SPRINGS IN REGIONS OF REMOTE VOLCANIC ACTIVITY (SERIES *B*).

The waters of hot springs in regions of remote volcanic activity, so far as is indicated by the analyses available, carry much smaller amounts of dissolved salts than either of the other two series. The total salts dissolved is less than 9 per cent. of the average of analyses of hot springs in regions of relatively late volcanic activity and less than 4 per cent. of the total salts dissolved in mine waters. Bicarbonates predominate, sulphates are found in appreciable amounts, chlorides are sparingly present. The positive ions are mainly calcium and magnesium with only a little soda and potash. Metals are very sparingly present. These waters offer almost as striking a contrast to mine waters as to waters of hot springs in regions of late volcanic activity. Since they are from regions in which volcanic processes are not known to have been active in late geologic time, it appears probable that they are merely ground water that has become heated in depth.

[1] Clarke, F. W., "The Data of Geochemistry," Bull. U. S. Geol. Survey No. 491, p. 113.

MINE WATERS (SERIES *C*).

The mine waters of which analyses are available are comparatively simple in character. Only chlorides, sulphates and carbonates are present in appreciable amounts. The other negative ions exist in traces only, and these are reported in comparatively few analyses. Two of the solutions analyzed are concentrated. One of these is from the Mountain View mine, Butte, Montana, and the other from the Central Tunnel of the Comstock Lode. The first is essentially a concentrated $CuSO_4$ solution and the second a sulphuric acid solution of iron, calcium, magnesium, and aluminum sulphates. If these two analyses were omitted the average would still be dominantly sulphate, though these two contain over 88 per cent. of the total SO_4, none of the CO_3, and a little less than 9 per cent. of the Cl.

Since these are largely oxidized waters, sulphur is reported in only two of the analyses, and in one of these it is possible that there had been reduction of sulphates by organic matter.

The metals present in mine waters differ greatly from those found in hot springs. Many metals that are not reported in waters of these hot springs occur in appreciable quantities in mine waters. Among them are copper, zinc, cobalt, cadmium, nickel and lead, with some analyses showing traces of gold and silver. Manganese, iron and aluminum are much more abundant and alkalies less abundant than in the hot waters of series *A*. The alkali earths, or calcium and magnesium, are intermediate in amount between the two series of hot waters.

If the two analyses of concentrated mine waters mentioned above were omitted, it would very materially alter the proportions of the three groups of metals, since these two waters carry 95 per cent. of the copper, which amounts to about 55 per cent. of all the metals present. They carry also about half of the iron, about 91 per cent. of the aluminum, about 52 per cent. of the manganese, 57 per cent. of the alkali earths, and about 15 per cent. of the alkalies. If they were omitted the percentage of alkalies would be increased considerably, the alkali earths would also be increased to some extent, and the other metals would be lowered

correspondingly, approaching more closely the thermal spring waters from regions of igneous rocks.

A group of mine waters, including all but five of those used to obtain this average, have been recently discussed by one of the writers in connection with the problem of sulphide enrichment.[1]

DISCUSSION.

As stated above, this inquiry was undertaken with a view of ascertaining the composition of waters that have been assumed to be the agents of deposition of sulphide lode ores, particularly those of copper, gold, and silver, in order that experimental work might be conducted as nearly as practicable under natural conditions. No comprehensive discussion of the genesis of lode ores is aimed at here, but a few of the more obvious relations will be mentioned.

The series of mine waters represents solutions that are capable of dissolving all of the important metals, at least in an oxidizing environment, and moreover the metals in a reducing sulphide environment are precipitated. The waters themselves carry copper, iron, and zinc, and a few of them carry lead, silver, and gold.

On the other hand, the waters of hot springs carry the metals very sparingly. If an investigator should approach the subject having as data only these analyses (series *A* and *B*), and a knowledge of the composition of the ores, very likely he would not see a genetic relationship between them. Any argument that is based solely on the composition of waters and of ores is not convincing, for the more valuable metals are practically unknown in these analyses. Moreover iron, manganese, and barium, elements that are commonly found in abundance in the lode ores, are but sparingly present. Some significance may be attached to the presence of the bromine, fluorine, boron, arsenic, antimony, sulphur and silica, since these substances are present in many lode ores. Silica is more than twice as abundant in series *A*, as it is in mine waters, and, expressed in percentages of total solids, is

[1] Emmons, W. H., "The Enrichment of Sulphide Ores," Bull. U. S. Geol. Survey No. 529, 1913, pp. 60–73.

more than seven times as abundant. Iron and sulphur appear only in subordinate quantities.

It is well known, however, that some hot springs have deposited the metals, at least in subordinate unworkable quantities. At some places the spring deposits are closely associated with existing springs, and should be considered in connection with the composition of the latter. At Ojo Caliente, New Mexico,[1] Lindgren has shown the connection between hot waters which now issue, the tufa deposits, and the metalliferous ores that occur in the fissure along which the spring waters probably rise to the surface. At Wagon Wheel Gap, Colorado,[2] hot waters carrying alkali chlorides, sulphates, carbonates and heavy metals issue from two springs which are located along a fissure which is filled with barite, fluorite, silica and metallic ores. At Boulder Hot Springs, Montana,[3] in the material deposited from hot springs precious metals up to one dollar a ton are found.

Since the metals are only sparingly present in the waters of the hot springs and since there are many reasons for supposing that they have been deposited from such waters, it is pertinent to consider the probable composition of these waters before the metals were deposited. In the first place the waters are alkaline. This is probably true of nearly all the waters from deep sources. If they had been acid at their source they would have become alkaline by reactions in the alkaline environment which prevails at depths. Moreover, it appears probable that the sulphates have been formed by oxidation of sulphides, and if it is assumed that all of the sulphate has so formed, the sulphide ion before oxidation to sulphate would be equal to about 6 per cent. of the total solids. Carbonate also is probably present in excess since many hot springs in the regions of late volcanic activity yield abundant carbon dioxide. This is mentioned in many analyses, although only the carbon dioxide expressed as carbonates is shown in most of the analyses. The ascending hot waters, being alkaline, would be capable of dissolving silica readily and of precipitating it where alkalinity diminished. Thus, oxidation, as well as

[1] Lindgren, W., ECON. GEOL., Vol. V., p. 22.
[2] Emmons, W. H., and Larsen, E. S., ECON. GEOL., Vol. VIII., p. 246.
[3] Weed, W. H., XXI. Ann. Rept. U. S. Geol. Survey, Part II., p. 233.

decrease in temperature and pressure and dilution with cold ground waters, would cause precipitation of SiO_2.

These solutions have without doubt been greatly diluted by mingling with surface waters, to what extent it is impossible to estimate. It may reasonably be assumed that before partial oxidation and dilution the hot spring waters were mixtures of alkali chlorides, alkali carbonates, and alkali sulphides in which the chlorides predominated. The alkali chlorides will dissolve iron, copper, gold, lead, zinc, and mercury, as well as antimony and arsenic. Silver is only slightly soluble except in a concentrated alkali chloride solution, but gold will dissolve forming with KCl a soluble salt, probably $KClAuCl_3$, or with NaCl a corresponding sodium salt. Lead forms a somewhat similar compound, $KClPbCl_2$, in hot concentrated alkali chloride solution. Thus, a chloride solution would itself be capable of transporting all of these metals.

Carbonate solutions with excess CO_2 will dissolve iron, copper, silver, zinc, and mercury. With high pressures and excess CO_2, lead also is dissolved. So far as we are able to ascertain, gold is not dissolved in carbonate solutions unless alkaline sulphides or chlorides are present.

A solution of alkali sulphide will dissolve iron, gold, lead, zinc, and mercury. Antimony and arsenic also are very soluble in alkali sulphide solution and in a concentrated solution copper is dissolved. It is noteworthy that the presence of antimony and arsenic in an alkali sulphide solution increases the solubility of copper. As recently emphasized by Victor Lehner,[1] the alkali sulphides as well as the alkali chlorides are doubtless important agents in the deposition of primary gold ores. The experiments of Lehner show that while gold may be precipitated very readily from chloride solution by pyrite and other metallic sulphides, pyrite will not throw down gold from alkaline sulphide solutions.

Let us consider the changes that may take place in a solution of alkali chlorides, alkali carbonates and alkali sulphides, carrying various proportions of the metals, coming into a region of cold oxygenated waters. Sulphates would be formed from sulphides,

[1] Lehner, Victor, "Transportation and Deposition of Gold in Nature," ECON. GEOL., Vol. VII., December, 1912, p. 744.

and insoluble sulphates, like barite, would be precipitated. As sulphates accumulated the waters would become less alkaline; if iron and sulphur are present in solution, nearly neutral ferrous sulphate would form. By the accumulation of ferrous sulphate, gold would be precipitated from solution. Possibly silver would be precipitated also, as native metal by the accumulation of ferrous sulphate. The concentration of ferrous salt must be greater, however, for the precipitation of silver than for the precipitation of gold, and so far as indicated by the deposits themselves, native silver is exceedingly rare and possibly altogether absent in primary sulphide ores. Native silver is considered almost universally as secondary because it generally disappears in depth, but it is obvious that a relation to depth might follow precipitation that attends partial oxidation.[1] In view of the efficiency of ferrous sulphate as a precipitant of gold and silver, it is not surprising that the sinter deposits of hot springs carry these metals so sparingly. As emphasized by Becker,[2] metals are probably deposited from alkali sulphide solutions merely by dilution.

Summarizing the causes of precipitation, the following may be mentioned: reactions with wall rock, decrease of temperature, decrease of pressure, dilution, and oxidation. As has been stated by Lindgren,[3] the deeper deposits, that is those formed at considerable depths below the surface then existing, may carry copper, but as a rule they carry little silver. On the other hand most of the deposits that carry silver most abundantly are those which have been formed near the surface. At least these relations will hold in the United States. Gold, however, is formed at great depths and also near the surface. It appears probable, therefore, that copper is precipitated mainly by decrease of pressure and temperature, whereas silver, in a larger measure, has been precipitated by processes directly related to oxidation and dilution.

[1] Ransome, F. L., "The Geology and Ore Deposits of Goldfield, Nevada," Professional Paper No. 66, U. S. Geol. Survey, 1909, p. 174.

[2] Becker, G. F., "Geology of the Quicksilver Deposits of the Pacific Slope," Mon. U. S. Geol. Survey No. XIII., p. 419.

[3] Lindgren, Waldemar, "Metallogenetic Epochs," ECON. GEOL., Vol. IV., 1909, p. 419.

SOME NOTES ON TITANIFEROUS MAGNETITE.

STOPFORD BRUNTON.

For some years, the exploitation of titaniferous magnetite ore bodies has been a question of some importance both to geologists and metallurgists. In 1867, a company was formed for the smelting of the famous titaniferous iron sands on the north shore of the Gulf of St. Lawrence. This company became bankrupt in 1877 after a large expenditure of labor and money, although at first sight the problem seemed to show every prospect of success, owing to the ease with which the sand might be obtained and magnetically separated. In northeastern New York, the titaniferous magnetites have also been worked, but at a loss and in no large quantities.

Since metallurgy has been so much developed, and the introduction of the electric furnace together with a better knowledge of slag formation has rendered successful smelting more nearly attainable, the problem of the relation of the titanium to the iron in the ore has become of increasing interest, and more work is being done on the problem year by year.

The following paragraph is an extract from the *Journal of the Iron and Steel Institute,* No. 1, 1910:

"R. H. Lee is supposed to have had good results at the Colorado Steel & Iron Company's furnaces at Pueblo during an experimental run of six weeks. At Norton on the Tyne, titaniferous ores containing 40 per cent. of titanium were smelted regularly in 1869 to 1876. . . . H. A. Rossie has demonstrated the possibility of smelting titaniferous ores, and is said to have manufactured a few hundred tons of pig iron containing 14 per cent. of titanic acid, which, when added in the open hearth furnaces to other grades of iron, give a product harder than chromium steel. It has been demonstrated that these ores can be smelted electrically to produce good pig iron, but electrical smelting cannot at present be considered beyond the experimental stage, and cannot compete with ordinary smelting methods."

From the foregoing paragraphs it will be seen that, although titaniferous iron ore has in the past been reckoned as of no commercial value and is at the present time being worked on a comparatively small scale, yet in the near future it will probably prove to be an important source of valuable ore. It will also be noticed that the period during which the titaniferous ore was smelted at Norton on Tyne was not as long as that during which operations were conducted with the St. Lawrence sands, which are quoted as carrying 33 per cent. TiO_2 in places. In both of these localities the use of the ore was eventually discontinued. These experiments therefore do not imply that the ore was easy to use and the fact still remains that, up to the present time in practice, titaniferous iron ore has not been made use of commercially on any large scale.

Professor W. Campbell, of Columbia University, New York, made in 1904 some microscopical examinations of certain titaniferous magnetites which showed the occurrence of a mineral which had apparently different properties from magnetite and was seen in the form of plates, needle-like forms and crystals, showing sometimes a zonal structure. This mineral was however not identified at the time.

The author was examining some titaniferous magnetite from the west coast of Newfoundland and the north shore of the Gulf of St. Lawrence during the latter part of 1912 and noted needle-like forms, plates and zonal structures, whereupon Dr. Campbell approved of the suggestion that an attempt be made to identify this mineral, and to find out if possible how the titanium occurs in the ore, and its relation to the magnetite.

At this same time, Dr. Joseph T. Singewald was carrying on under the Bureau of Mines in Washington the investigations upon the titaniferous magnetites of which a summary was presented at the New Haven meeting of the Geological Society of America, in December, 1912, and which has been since published in ECONOMIC GEOLOGY, Volume VIII., 1913, page 207.

The results here set forth were obtained independently, however, and are offered in the further development of a subject which is both of scientific interest and of practical importance.

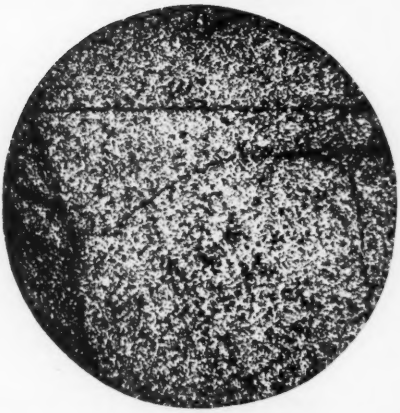
EXPLANATION OF PLATES.

Plate XI.

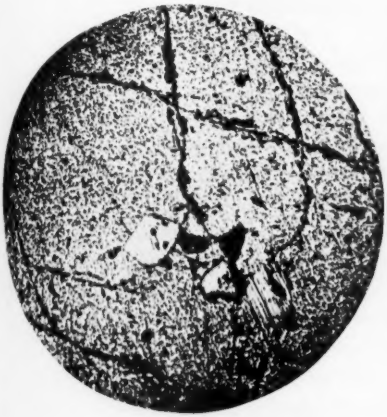
No.	Description	Condition	Titanium Per cent.	Remarks
1	Magnetite crystal.	Unetched	x	Typical of all unetched specimens.
2	Magnetite crystal.	Etched	x	Showing uniformly etched surface.
3	Ilmenite crystal, Ilmen Mts.	Unetched	45.93	
4	Ilmenite crystals, Ilmen Mts.	Etched		Showing slight etched effect of HCl acid on Ilmenite.

PLATE XI.

1



2



3

4

For the purpose of insuring uniform results, polished sections were made of ore taken from the following localities, thin sections were made from the same specimen, and analyses were made from the same fragments of ore as those from which the sections were made as follows:

Locality.	Per Cent. Titanium by Weight.
1. Mineville, New York	None
2. Lake Mahopac, N. Y.	0.06
3. Hurd Mine, N. J.	0.09
4. Swamp Vine, Ringwood, N. J.	0.09
5. Stephensville Crossing, Newfoundland	0.48
6. Mine Hill, Cumberland, R. I.	0.60
7. St. Georges, Newfoundland	0.63
8. Lake Sanford, N. Y.	0.84
9. Iron Mountain, Wyo.	1.65
10. Club House, Adirondacks	1.83
11. Locality (?), Adirondacks	2.85
12. North Shore, St. Lawrence Gulf	8.65
13. Canes Bed, Canada, West	14.00
14. Cibolla Canyon, Colo.	17.89
Ilmenite Crystal, Ilmen Mtns., Russia	45.93 (Dana)
Ilmenite, Roseland, Va.	
Rutile, Roseland, Va. Yellow in thin section.	
Rutile, Nelson Co., Va. Opaque in thin section.	

The method employed for polishing was as follows. A fragment of ore, roughly 1 in. square, ½ in. thick, was polished smooth on one face, being first ground down on a grindstone, then smoothed on iron plates covered with moistened carborundum powder, three grades of powder being used, coarse (80) mesh, medium (3F), and fine. The section was then polished on French polishing paper, (Hubert) Nos. 0, 00, and 000, being finally finished on broadcloth covered with moist rouge.[1]

Each specimen was first polished and then broken into two pieces, one of which was examined plain, while the other was etched rather deeply with hot, concentrated hydrochloric acid. The concentrated hydrochloric acid was found after several trials to be the only acid adapted to the purpose, and in order to make sure that the specimens were thoroughly etched they were boiled

[1] W. Campbell, ECONOMIC GEOLOGY, Vol. 1, p. 751.

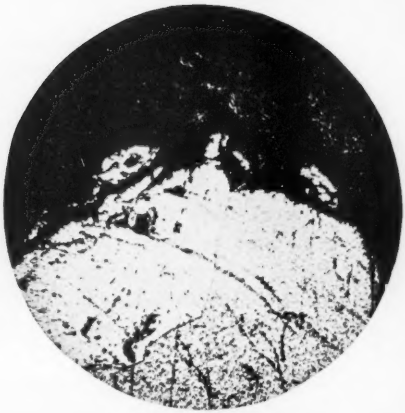
PLATE XII.

EXPLANATION OF PLATES.

Plate XII.

No.	Description	Condition	Titanium Per Cent	Remarks
1	Ore from Hurd Mine, N. Y.	Etched	0.09	Showing variability of etching.
2	Ore from Lake Sanford, N. Y.	Etched	0.84	Showing variability of etching.
3	Ore from North Shore Gulf of St. Lawrence.	Etched	8.65	Showing laths of unetched material.
4	Ore from North Shore Gulf of St. Lawrence.	Etched	8.65	Showing laths of unetched material.

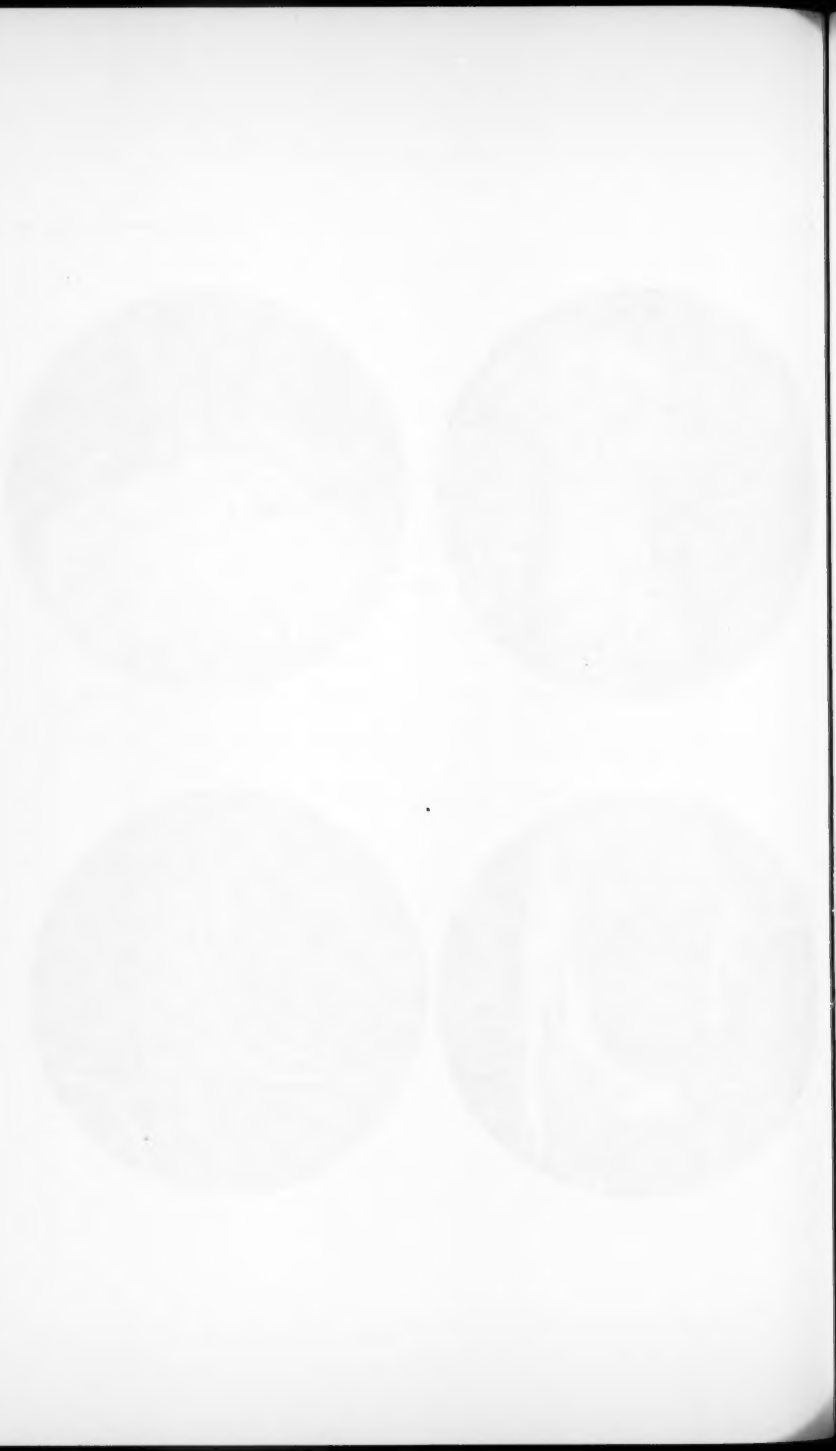
1



2

3

4



in the acid for a short time. The plan of using two polished specimens was adopted as it was found extremely difficult to etch one half of the specimen in this manner without affecting the other half.

The unetched specimen, on examination, showed a mottled surface without any distinctive difference of appearance between the two minerals. It was found practically impossible, owing to the nature of the ore, to get a completely polished surface, such as is obtained from a piece of commercial iron or steel, as, no matter how much care was exercised, parts of the ore would be polished and parts which were not so prominent would appear dull, giving the ore a mottled appearance. Those portions of the surface which had been polished had an appearance very much like that of ordinary ferrite in commercial iron, while the unpolished portions showed merely a dull surface, due to the poor reflection of the light.

The etched specimen, when examined under the microscope, showed certain grains still unetched, these grains retaining a bright and unaltered surface, while others in the specimen were observed to have been attacked by the acid and etched so as to bring out variations in relief. The unetched material was distributed through the specimen either in the form of plates or lath-like forms. It was thought that these were probably plates cut through in such a manner as only to show the edge. These lath-like forms were seen in many instances to intersect one another at angles varying from 45° or less, up to 90°, and gave the impression that the unetched material had crystallized out in the interstices between the faces of the magnetite crystals, or along the gliding planes. The plates themselves show no definite crystalline boundaries, but in some cases the zonal structure was very plainly defined. Other sections showed the unetched material distributed irregularly through the slide in patches of varying size.

It seems to be certain that the substance which remains unetched is different from the magnetite (which is attacked by the HCl), and the characters of the substance seem to indicate that

EXPLANATION OF PLATES.

Plate XIII.

No.	Description	Condition	Titanium Per Cent.	Remarks
1	Ore from Saint Georges, Newfoundland.	Etched	0.63	Showing laths of unetched material.
2	Ore from Saint Georges, Newfoundland.	Etched	0.63	Showing plates and patches of unetched material.
3	Ore from Stephensville Crossing, Newfoundland.	Unetched	0.48	Showing zonal structure.
4	Ore from Stephensville Crossing, Newfoundland.	Etched		Showing zonal structure.

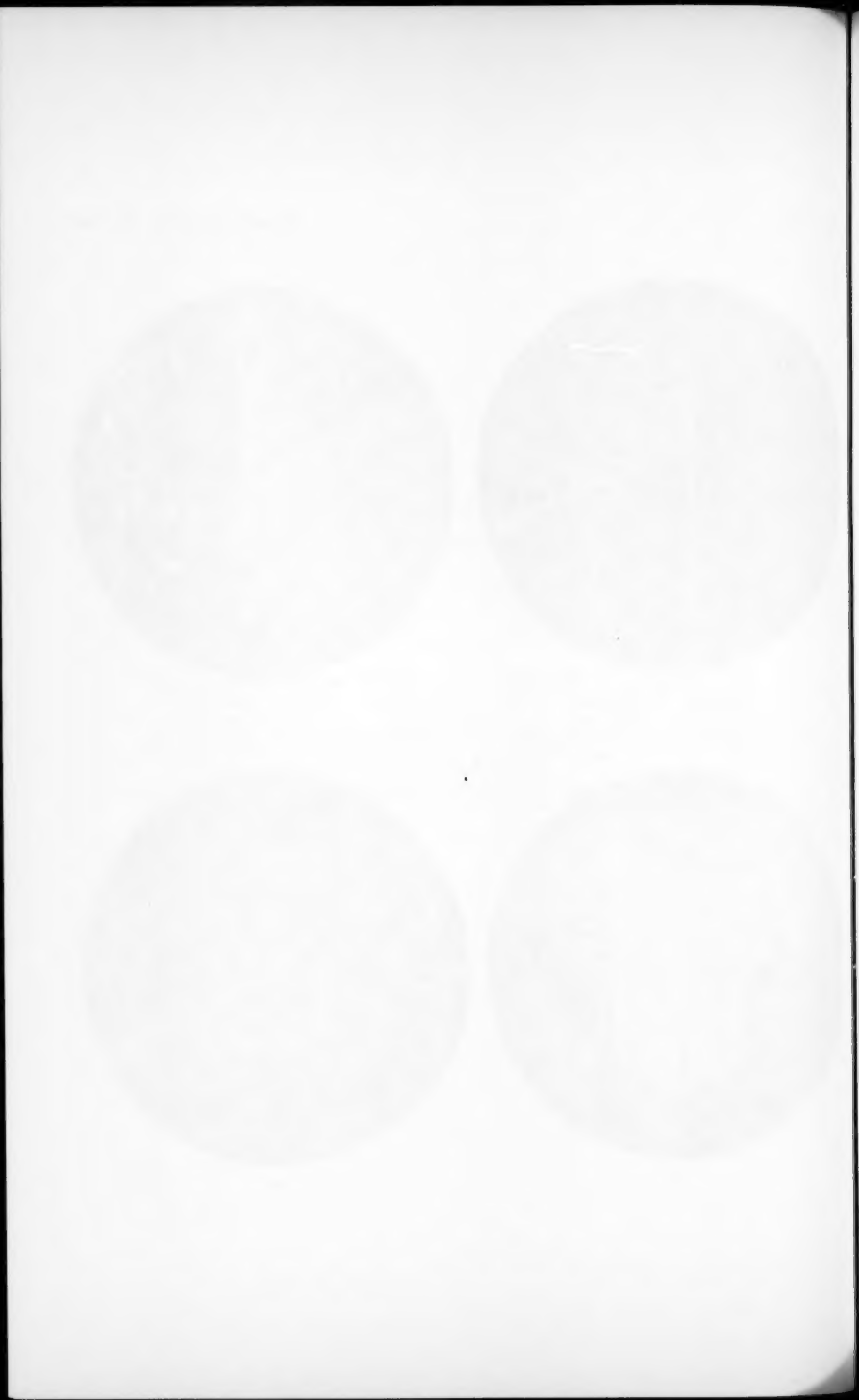
PLATE XIII.

1

2

3

4



it is either ilmenite, titanite, rutile, or some allied mineral containing TiO_2. An endeavor was made to find out whether this substance was ilmenite ($FeTiO_3$) or some other material, and to do this the following experiments were made.

Firstly, polished sections of ilmenite and rutile were taken and examined by reflected light under the same conditions as the titaniferous magnetite. The ilmenite showed a white surface, while the rutile had a reddish tinge.

Secondly, each specimen was etched with hot concentrated HCl, but this had no effect upon either of the minerals, and when reëxamined no distinctive difference could be marked under reflected light.

Thirdly, thin sections were made from the specimens of ilmenite, rutile, and from fragments of the ore taken from each polished section.

The sections of the various specimens of ore showed, in addition to the magnetite and ilmenite (when present), the following minerals as small inclusions in the ore:

2. Lake Mahopac, N. Y. ..... Augite which is almost non-pleochroic.
3. Hurd Mine, N. Y. ..... Felspar.
4. Swamp Vein, Ringwood, N. Y. ..... Quartz, biotite and felspar altering to sericite.
5. Stephensville Crossing, Newfoundland. Felspar altering to secondary products.
6. Mine Hill, Cumberland, R. I. ..... Felspar altering to sericite, chlorite and zoisite.
7. St. Georges, Newfoundland ..... Spinel and an alteration product of high double refraction (possibly steatite?).
8. Lake Sanford, N. Y. ..... Plagioclase felspar, biotite, pyrite.
9. Iron Mountain, Wyo. ..... Spinel and a brown alteration product.
10. Club House, Adirondacks ..... Spinel, biotite and titanaugite.
11. Locality (?), Adirondacks ..... Plagioclase felspar and biotite.
12. North Shore, St. Lawrence Gulf..... Spinel and brown alteration product.
13. Canes Bed, Canada, West ..... Chlorite.
14. Cibolla Canyon, Colo. ..... Plagioclase felspar stained with iron.

The above table demonstrates that in no case was a mineral found which in any way resembled titanite, common rutile, or any titanium bearing mineral, except in the case of number 10 where some titanium occurs in the augite but this small quantity would not account for the whole amount of titanium. It therefore follows that the titanium, in these specimens at any rate, appears in the ore as a component of the grains of the iron mineral.

The ilmenite showed exactly the same properties as magnetite and, as no leucoxene was present, it could not be differentiated from the magnetite.

The section of rutile from Roseland, Va., showed yellow in color with very high birefringence and the typical twinning lamellæ.

The section of the highly iron bearing rutile from Nelson County, Va., showed an opaque black substance in no way differing from magnetite or ilmenite. Thus it will be seen that rutile varies very much according to the amount of iron contained in it, till at a certain stage it probably grades into a mineral composed of iron with a certain percentage of TiO_2 in it. Certain sections, as that from the Hurd Mine, N. J., Lake Sanford, N. Y., when etched, showed that the grain had not remained entirely unetched as would an ilmenite grain, nor had they been etched to a dull black like the magnetite grains but each grain had been affected to a different degree.

The facts therefore are that the rutile alters from a translucent material in thin section (with a small iron content) to an opaque black mineral (with high iron content) in no way differing in its optical characters from ilmenite. Again the magnetite etches to a dull black color, the ilmenite remains bright and unetched, and apparently the etching effect is of a gradational character between these two limits.

The explanation here offered to account for these phenomena is that Fe_2O_3 is partially soluble in TiO_2 in the solid state when crystallizing from fusion and TiO_2 is partially soluble in Fe_2O_3. This solubility gives rise to different varieties of rutile on the one

hand and on the other to a titaniferous iron mineral which is not true ilmenite but which has properties lying between those of magnetite and ilmenite.

The argument might be put forward at first that the apparent variations in the amount of etching were due to the different orientation of the grains or to numerous small particles of ilmenite scattered through the grain. If this was true however the relatively large amount of TiO_2 in the ilmenite particles would raise the amount of TiO_2 in the grain and thus cause the iron as a mass to have a fairly high percentage of titanium. In cases however where this varied etching effect is noticed and the amount of TiO_2 from analysis is low, the idea that the mineral is a titaniferous-iron mineral with a lower percentage of titanium than true ilmenite seems more readily to explain the phenomenon.

The relationship in which the particles occur is submicroscopic and is so intimate that no mechanical means such as fine grinding and magnetic separation would be capable of separating the Fe_2O_3 and TiO_2. The separation is also rendered impracticable by the existence of this titaniferous-iron mineral which would probably not be so magnetic as magnetite but would be more so than ilmenite.

The number of specimens examined is small so that from such results no definite statements can be made with regard to generalities and it is quite possible the ores will be found containing the titanium in the form of rutile or titanite or some such mineral. On the other hand the localities from which the ores have been taken are widely removed from each other and in the analyses the titanium percentage is variable but in spite of these facts the titanium always occurs in these ores in the form of ilmenite or if not true ilmenite, as some other titaniferous-iron mineral.

The photographs show the variations in the amount of titanium and the corresponding variations in the relative amount and position of unetched material in the polished section, as well as the zonal structure in the grains before referred to. Five types of ore seem to be represented in which:

1. The magnetite crystals are etched to a uniform surface.
2. The grains all appear to be etched but to a varying extent.
3. The ilmenite appears with the magnetite in the form of laths.
4. The titaniferous iron appears as patches in the magnetite.
5. The zonal structure is apparent.

From the study of the ores certain conclusions are drawn; namely, that the titanium is not associated with the iron in such a way that ilmenite and magnetite are formed but the ore is composed of a titaniferous-iron mineral in which the amount of titanium varies. Furthermore the true magnetitic particles, those containing a small percentage of titanium, and those which are more nearly of the composition of ilmenite are so intimately mixed that they cannot be separated by magnetic concentration and the TiO_2 would have to be removed from the ore in the process of smelting.

GAS AND OIL WELLS NEAR OBERLIN, OHIO.

GEORGE D. HUBBARD.

Since the remarkable development of oil and gas in the "Clinton sand" at Bremen,[1] Ohio, there has been much exploration both northward and southward approximately parallel to the strike of the Clinton formation. Less than two years ago the exploration had reached as far northward as Oberlin; and now, at the end of 1912, this locality has been found to belong to the productive territory.

The wells here are in three townships, one west, Henrietta township, one south of the town of Oberlin, Pittsfield township, and the third the township of Russia, which also contains the village of Oberlin. Most of the wells are in the second township. They are becoming numerous enough soon to delimit pools and definite areas; but this will not be attempted just at present.

The topography is a very youthful, almost featureless, till plain 800 feet above sea level, with a few valleys about fifty feet deep.

The geologic section is quite uniform in the main lines, but shows interesting local variations. Table I. gives the correlated logs of sixteen wells. An average section is as follows:

Average Geologic Section.	Thickness, Feet.	Depth to Bottom of Formation Feet.
Glacial Drift.—In lower part often stratified, sometimes fine quick-sand; in upper part bouldery yellow to buff till, underlain by blue compact bouldery till	78– 153	78– 153
Shale: including most of the Bedford[2] (Mississippian) and the whole of the thin-		

[1] Bownocker, J. A., ECON. GEOL., Vol. VI., pp. 37–50, 1911; Geol. Surv. Ohio, 4th Ser., Bull. 12.

[2] Some Bedford may be included in the portion called drift from some wells, where Bedford is soft enough to be driven through.

Average Geologic Section.	Thickness, Feet.	Depth to Bottom of Formation, Feet.
bedded Ohio (Devonian) shale. The former is generally greenish or purple. The latter is usually black with a bluish or greenish soft phase in middle portion. It often carries considerable gas.	740– 822	870– 925
"Big Lime."—Includes the rest of the Devonian and most of the Silurian. From the top downward, first the Olentangy if it occurs in this part of the state, as seems probable, then the Delaware and Columbus formations completing 150 to 200 feet of Devonian limestones and shaly limestones. Then comes the Monroe group,[1] varying from argillaceous limestone to very pure dolomitic rock with beds of salt, and near the top abundant water which must be shut off: next below, the Niagara group[1] essentially all dolomitic limestone.	1,160–1,215	2,047–2,112
Clinton formation.—(*a*) Shales, calcareous shales and limestones generally brown, red, or white, thin bedded, also thin flinty sandstone beds; the latter called shell by well men Sometimes two "shells" occur varying in thickness from one to four or five inches The limestones vary from one to fifty feet.	24– 117	
(*b*) Sandstone, loose friable rock consisting essentially of rounded grains of quartz sand, from one-tenth to one-thirtieth of an inch in diameter; considerable pore space; sometimes wanting, sometimes with shale parting; carries the oil or gas when these are present	0– 34	
(*c*) Argillaceous and arenaceous thin-bedded limestone and shales found wherever the well runs below the sand.	100±	2,300±
Total Clinton formation	250±	

[1] Prosser, C. S., Geol. Surv. Ohio, 4th Ser., Bull. 7, pp. 25–28, 1905.

Table I.—The wells are numbered chronologically as drilled. By reference to the map (Fig. 1) the location of each can be ascertained. Well No. 14 was drilled in Henrietta township, about eight miles northwest from this group. It was a dry hole, but was 2,050 feet deep, ending in the so-called Red Rock. It penetrated 1,180 feet of the "Big Lime," almost exactly the average thickness found in this group of wells. It found no sand in the Clinton and only about 150 feet of the Clinton formation as against 200 and 293 in wells Nos. 4 and 8.

The first figure gives the altitude of the ground at mouth of the well, from which it is possible to calculate the altitude of the various horizons with reference to sea level. (See Table II.)

(*a*) In but two cases is the entire thickness of beds below sand and above the "Red beds" (Medina?) penetrated; hence, the thickness of the Clinton is known only in the two.

(*b*) Owing to the abundant flow of gas from the sand in these three wells, practically no drilling was done below the base of the sand.

(*c*) Not an average but the actual thickness in the only wells deep enough to include all the formation.

(*d*) Not the total thickness, but the amount of the formation penetrated in each of two cases. No well has been put through it.

(*m*) In this well the 5⅛ casing reached twenty feet below the base of the "Big Lime" to shut out water encountered at the base.

(*x*) Gas found at several horizons in several wells but exact depth not noted in the logs.

Some gas with feeble flow is occasionally found in the drift. Many wells in the vicinity draw gas from the long shale section at various horizons. One of the wells completed in the shale recently, showed rock pressure of 180 pounds and a very satisfactory supply for personal domestic use.

A showing of oil and considerable gas is often found in the "Big Lime." In some wells this is near the top; in one, the gas blew strongly from near the bottom. This was shut off before drilling down to the Clinton. As shown in the section, the "Big Lime" is remarkably uniform in thickness, and is very nearly level. Over the area tested the top varies from 75 to 150 feet below sea level, and the bottom varies between 1,258 and 1,348 feet below sea level. These depths are but little changed even as far away as at Elyria and the western part of Cleveland. Wells three to seven miles northeast of Elyria find the base of the lime at 1,420 feet below sea level, and the Winton Company well at the western limits of Cleveland twenty-five miles north-

TABLE I.

Number of Well.	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17	Thickness Aver.	Rocks.
Mouth of well above sea level	750	784	784	755	745	750	784	792	792	784	802	801	750	780	800	790		
Drift—10 inch drive pipe	92	145	98	83	92	95	139	134	104	153	144	127	78	145	135	129	118	Drift
Shale water	170	185	....	....	....	....	....	....	....	....	....	....	....	....	....	....		
8¼ inch casing	170	185	....	....	....	175	....	(x)	160	....	....	....	....	....	180	....		
Shale gas, 1st	....	....	240	....	....	....	....	(x)	....	(x)	....	....	....	....	....	....	777	Shales: Ohio–Bedford
Shale gas, 2d	....	....	900	....	....	....	....	(x)	....	....	....	....	....	....	....	....		
Top of "Big Lime"	890	925	920	870	885	895	904	890	880	905	888	880	900	905	875	910		
First water	1,130	....	1,156	1,075	....	....	....	....	....	1,105	....	....	....	....	....	....		
	1,150	....	....	1,130	....	....	....	....	....	....	....	....	....	....	....	....		
Big, or second water	1,171	1,200	1,185	1,160	1,178	1,173	....	....	1,170	1,180	1,137	1,165	1,180	....	1,170	1,200		
Length of 6⅝ in. case	1,200	1,235	1,217	1,224	1,225	1,220	1,273	1,235	1,240	1,275	1,207	1,217	1,255	1,255	1,210	1,245		
			Found in	1,485–93		Found.	....	....	....	....	....	....	....	....	....	....		
Salt	1,600	both.	Depth	1,501–16	Depth not		1,515	....	1,500	....	....	....	....	....	....	....	1,184	Limestones: Niagara–Monroe–Columbus–Delaware
		not	given.	1,640–44	reported.		1,545	....	....	....	....	....	....	....	....	....		
Showing of oil	....	....	....	1,830	....	1,920	....	....	....	....	....	....	....	....	....	....		
Big water	2,030	....	1,920	2,019	2,050	2,048	....	....	1,950	....	....	....	(m)	....	....	....		
Length of 5⅛ in. casing	2,050	....	....	2,047	....	2,058	....	....	....	....	....	....	2,108	....	....	....		
Gas, blowing	....	....	....	....	....	2,058	....	....	....	....	....	....	....	....	....	....		
Base of "Big Lime"	2,060	2,112	2,080	2,047	2,070	2,098	2,096	2,070	2,095	2,110	2,065	2,060	2,088	2,095	2,061	2,085		
"Little lime"	2,090	2,142	....	2,068	....	....	....	....	2,125	2,140	....	....	....	2,133	2,090	2,125		
	2,128	2,172	....	2,124	....	....	....	....	?	?	....	....	....	....	2,120	2,145		
Shell	....	....	....	....	....	2,112	....	....	....	....	....	....	....	....	....	....		
Shell	....	....	....	....	2,173	....	....	....	....	....	....	....	....	....	....	....		
Top	2,150	2,202	....	....	....	2,122	2,193	....	2,188	2,205	2,131	....	2,163	2,182	2,155	2,172	200–	
	....	....	....	....	....	....	....	....	....	....	2,141	....	....	....	....	....	293	
Clinton sandstone	....	....	2,197	None	None	Clay	....	None	Shale	....	Shale	2,120	....	....	....	....	(c)	Calcareous shales: Clinton formation
	....	....	(Trace)	....	....	Parting	?	....	Parting	....	Parting	(Trace)	....	....	....	....		
	....	....	....	....	....	2,156	....	....	....	....	2,159	....	....	....	....	....		
Bottom	2,160	2,230	....	....	....	....	....	....	2,217	2,214	2,163	....	2,171	2,192	....	2,184		
Shales below sand bed (a)	2,170	2,288	2,299	2,340	2,224	2,226	2,238	2,270	2,265	b	2,173	2,202	2,181	b	2,200	b		
Top of red rock	....	....	....	2,340	....	....	....	2,270	....	....	....	....	....	....	....	....	(d) 50–	Red Rock
Bottom of hole	2,170	2,288	2,299	2,390	2,224	2,226	2,238	2,385	2,265	....	2,173	2,202	2,181	....	(?)	....	115+	
Success	Gas	Oil and Gas	Dry	Dry	Dry	Gas	Gas	Dry	Dry	Gas	Gas	Dry	Gas	Gas	Dry	Gas		

east found it at 1,380 feet below. Thus the "Big Lime" is not much warped to give synclines and anticlines.

There are several beds of salt in the Monroe group of the "Big Lime." A bed of eight feet is reported in several wells. In one hole three salt beds were found, "one of eight feet at 1,485 feet below sea level, a second of fifteen feet at 1,501 to 1,516 feet below, and the third of four feet at 1,640 feet below, with an aggregate thickness of 27 feet. Previously, salt had not been found west of Elyria.[1] This occurrence of salt beds in the "Big Lime" may be interpreted to mean that the Salina formation, thick in northeastern Ohio and thinning westward, has not entirely disappeared here; but the very thinness of the beds and inter-beds here as compared with those in Cleveland and eastward confirms the belief that the Salina is a great wedge in northeastern Ohio.

Gypsum also occurs in the beds designated "Monroe group" in the above section. The amount cannot be ascertained, but pieces occur in the samples at several horizons and they amount to half the sample from one screw length.

About 300 feet below the top of the "Big Lime" and 420 below sea level copious supplies of water are found. These are salty and so abundant as to require casing off at a depth of 1,200 to 1,225 feet below the surface. Since at least one casing beside the drive pipe is needed above this level to shut out water, a 6⅝ inch pipe is usually used to this depth. A ten-inch drive pipe is used. By using so large a pipe for shutting out the "Big Water" as the well men call it, there is still room for another casing, if necessary, before the gas or oil is reached.

In several of the wells an abundance of water is found within twenty or thirty feet of the base of the "Big Lime." In one well it rose to the mouth from a depth of 2,019 feet, or 28 feet above the base of the limestone. This water is reported at 1,920, 1,950, 2,050, 2,048, and 2,030 in other wells. It is not always present but must usually be cased out, thus making it impossible

[1] Bownocker, J. A., Geol. Surv. of Ohio, 4th Ser., Bull. 8, p. 39; ECON. GEOL., Vol. VI., p. 47, 1911.

to use a pipe larger than 3½ inches for the gas. While there is usually water enough with which to drill, it has been necessary to water the holes in the shales and some in the limestones.

Probably the Clinton formation is the most variable both in character and thickness, of any in the entire section. It is in some places largely a dark to black shale, in other places the shale is green, bluish, gray, or brown. In some holes the shale, always calcareous, makes up most of the formation, in others many limestone layers occur. These seem to be thin-bedded, white, red, or brown, and are called "shells" by some drillers, or when well developed they constitute the "Little-lime." The term "shell" is better applied to the dense sandstone layers of two or three inches in the formation. No limestone has been reported among the shales of the Clinton formation below the sand or sandstone bed, although the drill has been forced down 50 to 100 feet in shales; and in two wells through some 50 and 115 feet respectively of "Red Rock" (unidentified[1]) below the real Clinton. The Henrietta well, No. 14, also entered these, "Red Rock" beds some yards, and records of the three wells which go entirely through the Clinton beds suggest strongly its thinning westward from almost 300 feet in the east part of this field to only about 150 feet eight miles northwestward.

The sand which all drillers seek, and without which the well is only a hole, is never thick and when it exceeds ten to fifteen feet it has a shale parting or two; hence the drillers designate top sand, little sand, big sand, and bottom sand. The maximum number of "sands" reported in any one well is three. Occasionally it fails altogether. Then, of course, no gas is found. Because of the texture of the sand, and the lack of porosity the wells are greatly improved by shooting. This is accomplished

[1] These red beds have often been called Medina but so little is known of their character and of what may be below them that it seems best not to try at present to declare their place. They here consist of calcareous shales with considerable very fine quartz sand. Little or no cement except $CaCO_3$ and $(CaMg)CO_3$ is present, and this forms but a weak binder. If equivalent to the Medina of New York it more resembles, in texture, the Richmond, its probable equivalent in southern Ohio; while it more closely resembles in color the N. Y. Medina.

by discharging forty to eighty quarts of nitroglycerine at the sand level, at a cost of one hundred to two hundred dollars.

Depths have been carefully studied to ascertain if the anticlinal structures were related to the accumulation in this region. They are believed to have no significant relation to the occur-

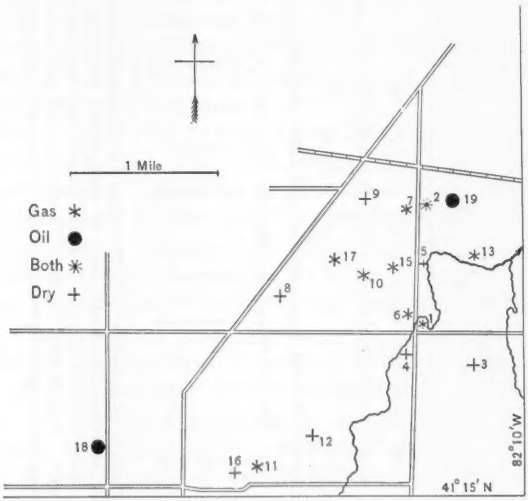


FIG. 56. Adapted from the U. S. Geological Survey Topographic Map. Well No. 1 lies about 3 miles southeast of the square in Oberlin. Wells Nos. 18 and 19 are now completed; the former has a little oil and gas, the latter 1,500,000 feet of gas.

rence of the oil and gas. The distribution of the product seems rather to follow the distribution of the sands. In three wells, only a trace of sand was found, but here it contained some gas, though not enough to pay for piping. Where sand is entirely wanting no gas is encountered; and the best flows come from the best development of sand. Only one well, No. 9, showed good sand without showing gas. It does not seem to matter whether the sand is high or low in the Clinton. A well producing over

TABLE II.

Number of Well.	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17
Depth of top of "Big Lime" below sea level	140	141	136	115	140	145	120	98	88	121	86	79	150	125	75	120
Depth of base of same below sea level	1,310	1,328	1,296	1,292	1,325	1,348	1,312	1,278	1,303	1,326	1,258	1,259	1,338	1,315	1,261	1,295
Variable interval between base of lime and top of sand	90	90	117	....	....	24	97	....	93	95	66	60	75	87	94	87
Depth of top of Clinton sand below sea level	1,400	1,418	(Trace) 1,413	No sand		1,372	1,409	No sand	1,396	1,421	1,324	1,319	1,413	1,402	(Trace) 1,355	1,382
Product	Gas	Gas Oil	Show-ing	Dry	Dry	Gas	Gas	Dry	Dry	Gas	Gas	Dry	Gas	Gas	Dry	Gas
Amount of flow (open well) cu. ft. per diem	1,000,000 Cu. ft. (Gas)	100,000 Cu. ft. (Gas)	Not piped.			1,000,000 +	1,000,000		Showing only	3,000,000	1,500,000	Showing only	2,000,000	5,000,000		6,000,000

Table II.—Gives altitude of several stratigraphic horizons with reference to a horizontal plane, sea level, from which any possible occurrence of synclinal, or anticlinal structure might be worked out. Note that the well reaching the sand at the highest level, 1,319 feet below sea level, is a dry hole and that all wells but one reaching the sand below the 1,400-foot level are good gas wells. Base of the "Big Lime" is given in each well and it may be used for calculations where the sand is wanting though not so advantageously, because it is not uniformly distant from the sand.

1,000,000 cubic feet per day has 24 feet of shales, etc., between the top of the sand and the base of the "Big Lime." Another which forced oil over the derrick several times before it was closed in, had 90 feet in the same interval and the base of the "Big Lime" was here farther below sea level than in any other well, save one. This was a 2,000,000 well in which the base of the "Big Lime" was ten feet lower still.

Further evidence that the gas comes from several small pockets of sand and not from an anticlinal structure is found in the diverse rock pressure in adjacent wells. No. 1 and No. 2, which are three quarters of a mile apart, each have a rock pressure of approximately 600 pounds. The second yields considerable oil without pumping. Well No. 15, about mid-way between wells 1 and 2, but some 600 feet off the line westward, tests 950 pounds. and has a flow of 5,000,000 feet. Table II. shows the depth of the Clinton sandstone layer below sea level. It does not seem to possess any synclines or anticlines, but is irregularly warped if continuous.

With the considerable development of the Clinton through this part of Ohio the question of Paleogeographic interpretation arises. No biologic evidence can be deduced because the beds have only been found by well drillings. Two facts, however, seem obvious: First, that the Ohio-Clinton[1] sea came farther north than formerly supposed, farther than mapped by Professor Schuchert. The beds are found in every county and in many parts of most counties from southern and middle Ohio northward to Lake Erie. Second, that even if the Medina-Richmond seas were extensive in this vicinity the Clinton seas seem to have had shallow oscillating waters and migrating shore-lines with shifting conditions in north central Ohio.

The presence of alternating shales, thin limestones, and discontinuous sandstones very strongly suggests varying conditions. With no continuous sandstone layers in this locality in the formation, but with thin sands at various horizons, one can easily be-

[1] Schuchert, Chas., "North American Paleogeography," *Bull. Geol. Soc. Amer.*, Vol. 20, p. 538, and pl. 64, 1909.

lieve these arenaceous deposits stand for beaches, sandbars, spits, etc., along the northern margin of the Clinton sea. It then follows that the oil and gas is a discontinuous accumulation in old beaches and shore deposits and is so uncertain because the sands are discontinuous. Further study of well records through northern Ohio is necessary to ascertain the tenability of the hypothesis.

THE COMPOSITION AND NATURE OF THE GAS.

No complete analysis of the gas is available, but a series of tests has been made which will serve most purposes.[1]

At the wells as the gas leaves the pipes some slight separation of component parts occurs. So considerable at some wells, is this, that a separator is attached to recover the oils that may be taken from the gas. One well (No. 2) yields large quantities of ordinary paraffin-base crude petroleum with the gas without pumping. A small amount of gasoline might be recovered from the gas, but no special effort is made to do so. Any that may separate at the mouth of the well is saved with the oil; the balance remains in solution in the gas and goes on into the pipes.

Carbon dioxide and sulphur are practically wanting in the gas, the latter fact contributing greatly to the comfort of those using it. Over 90 per cent. of the gas is methane, or Marsh gas, CH_4; the rest is mostly hydrogen. This makes a gas of high heating value. Tests have given repeatedly over 900 B. T. U. per cubic foot. It is the purpose of the men developing the field to thoroughly test all adjacent territory; and when this is done, maps of pools can probably be prepared.

[1] Tests made in various scientific laboratories of Oberlin College and data furnished by Professors F. F. Jewett and E. J. Moore.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

FIELD AND OFFICE METHODS IN THE PREPARATION OF GEOLOGIC REPORTS.

MEASUREMENTS BY COMPASS, PACE, AND ANEROID.

The Problem of Efficiency.

Sir: In the discussion of field and office methods of geologic work which is now going forward in this journal, perhaps something may be said with advantage on the factors which make for efficiency in the commonest means of location used by the geologist—traverses by pace and compass, and measurements of elevations by aneroid. To give a preliminary definition, efficiency consists in the attainment of the largest amount of results known to be of the necessary accuracy with the least expenditure of energy, time, and money. These factors must be balanced against each other. The use of a carriage or automobile during the day's work, for example, saves energy and time, but puts a premium on hasty and incomplete results. The use of the bicycle saves time and money at the expense of energy and accuracy.

For most kinds of field geology time and expense preclude detailed instrumental surveys and it is recognized that the best work is done on foot. In western mining districts provided with excellent topographic maps and where a horse may be made of large use extensive traverses by pace and compass are not demanded.

In the Appalachians, however, the country is wooded and fenced, a horse is of but little use, and the intricate structure requires detailed examination of outcrops distant from roads. Many of the topographic maps made twenty or more years ago are of so poor a quality in the mountainous regions that for accurate work no dependence can be placed upon the details of the topography. It is in such regions or in those without topographic maps that the demands on compass, pace, and aneroid methods are most exacting. It is only from working under these conditions that the writer came to an appreciation of many of the points set down in the following pages.

Means of Increasing Speed.

Much time may be lost in getting from camp or hotel to the point where work begins, in returning at night, and in moving headquarters. It is important that the geologist should travel quickly and arrive at his work fresh and full of energy. This is the first point in geologic methods on which the efficiency engineer would probably put his finger. The motorcycle could without doubt be made of large use in this respect. With it the worker could reach distances of twenty miles in the same time he would walk three. From one base 1,600 square miles could be reached with the same facility as 100 square miles by walking. The interest on the first cost and upkeep of motorcycles would be small when balanced against the daily expenditure for salary and transportation which other methods entail. The advantage over a horse is that the motorcycle is not eating when it is not working. There should be added to this the advantage of a more permanent headquarters and the possibility of different parties meeting nightly for conference; also the fact that actual geologic work would hardly be attemped from the motorcycle as the rider is fully engaged in studying the road. It would be used merely as a means of transport to and from work. Against these advantages however must be balanced the disadvantage of repairs and deterioration to the motorcycle and occasionally to its rider.

Having arrived at the point of departure for the day, the most

fundamental factor making for faster work to be impressed on the beginner is the acquisition of the habit of fast walking. The geologist spends a large part of his time and energy in moving his mind from observation point to observation point. In so far as he is not observing in transit it is lost time, except that it may be partly employed in thinking on the field problems. For vigorous walking the calf muscles must be employed, giving a push with the toes at the end of each stride. Long distance walkers, like Indians, toe straight ahead, not out. If the college saunter has ever been acquired by the young geologist it must be speedily eliminated. A civil service examination for a geologic survey might properly include a mark based on inspection of the peculiarities of wear of the shoes of the candidate, an old pair properly certified accompanying each paper.

I have read that the ever-scientific Germans have found by tests that an army accomplishes more in the end if a day of absolute rest intervenes between every four days of forced marching. In the geologic field the same end may be attained if the plans are so arranged that a day of easy work is arranged to follow after every few days of hard work, rather than to keep the same hard pace throughout the week.

In contrast to rapid walking, observations within the range of the problem should be made carefully, fully, and deliberately; and records should be made in the same way. The young geologist should feel that in doing this he is making the best use of his time.

The Probable Error of Results.

Geologists deal with the sums of measured quantities of distance, angle, or substance. All such measurements are subject to some error and according to the methods of combination of measurements that error may be increased or decreased. With the passage of geology into a more precise science it becomes more necessary that regard should be had for the theory of errors. The exact sciences of astronomy and physics have advanced to that stage where further progress largely rests upon the analysis of errors, their reduction to the smallest possible amount, and

the statement of the probable error of the results. Although at present most geologic problems are not of a nature to require such treatment, nevertheless as they commonly rest upon many measurements it seems desirable to have in mind the general laws of error. In so far as they relate to pace and compass traverses they may be summarized as follows:

Ruling out blunders, the small errors are of two natures, constant and accidental. A constant error is introduced into pacing if the length of his standard pace is misjudged by the geologist. The accidental errors are those due to difficulties of the course or lack of attention. In compass work a constant error is introduced if the wrong magnetic declination is set off and it is therefore of the first importance to know to the quarter of a degree the magnetic declination of any region at any time. Charts showing this for the United States are published by the United States Coast and Geodetic Survey. Accidental errors are due to the inevitable inaccuracies in sighting, or reading, or to small local deviations.

Constant errors in general are due to the personal equation or to lack of instrumental adjustment and must be eliminated or reduced by the forethought of the observer. They tend to acmulate with successive measurements in the same direction. Although accidental errors should also be reduced to a minimum, they cannot be wholly eliminated and they tend, contrary to the constant errors, to balance each other to a considerable degree. They can be investigated by the laws of probabilities as discussed in treatises on the method of least squares. It is sufficient here to state some general rules.

The location of a point is determined with respect to another point by a number of courses, each involving a measurement of angle and distance. The probable error of the result increases as the square root of the number of components. To illustrate,—let the probable accidental error of a single course be five feet. Then the probable error at the end of four courses is twice as great, or ten feet; at the end of 16 courses it is 20 feet; at the end of 64 courses it is 40 feet. With a small number of courses,

however, the less computable is the size of the error. For example, in four tosses of a coin heads would be quite apt to turn up from 0 to 100 per cent. of the throws. In 100 tosses heads would turn up approximately 50 per cent. of the times, as indicated by the theory of probabilities. It is not to be supposed therefore that in a traverse with a small number of courses the real error would be close to the probable error. A knowledge of the latter nevertheless may control the method of the work.

The Theory of Errors Applied to the Hand Compass.

The fundamental distinction between transit and compass measurements of angle is that in the latter an error in the direction of a single course is not carried forward as a constant error in angle but only as an error in location. The direction of every course is an independent quantity and the accidental errors of courses bearing in the same direction tend to partially counterbalance each other. The errors of courses in one direction do not, however, tend to counterbalance those of courses at right angles and only partially those at intermediate angles. The following discussion applies especially to courses bearing in one general direction.

Assume that the allowable error due to the angular measurements at the end of a traverse is 100 feet. If the traverse is a mile long and is made in a single compass sight the allowable error in sighting is 1° 5′, approximately one degree; the probable error should be not more than half this amount. If the traverse is measured in four courses of 1,320 feet, the allowable accidental error of each course is 2° 10′, giving 50 feet error in location for each course, or four per cent.; if 16 courses of 330 feet, the allowable accidental error of each course is 4° 20′, giving 25 feet error in location for each course, or nearly 8 per cent. For a sight of a mile a compass angle should therefore be read with four times the precision in order to attain the same ultimate accuracy as for a succession of courses 330 feet in length.

The probable error of a single reading of a hand compass with sights may be assumed as one degree, the probable error of a

reading without using sights as two or three degrees. The latter may be done much more quickly. A traverse consists of courses of variable length. The accuracy of the whole traverse is only very slightly diminished if the shorter courses have the angles measured with less care and more rapidity since the error in location is proportionately less than in the longer courses measured with much care and furthermore the errors in the short courses partially counterbalance. There is also a certain ideal length of course, since short courses consume more time in covering the same distance, long courses involve a greater error in location for the same error in angle. For ordinary traversing, sights near a quarter of a mile in length read by sights represent about this ideal compromise between time and accuracy. A sight as long as a mile should be made very carefully and checked if possible by an accurate backsight over the same course.

Use of the Compass in Traversing.

In making a traverse it is desirable so far as possible to make the stations definite objects, such as individualized trees, bowlders, etc. The course may then be measured with greater accuracy, the geologic detail filled in separately and the traverse recovered at any point at any future time. Such a method gives a large number of well-determined points, some of which may be used later from a distance for triangulation purposes.

Over long courses or on traverses where especial accuracy is desired backsights may be taken as a check and the average of backsights and foresights used. The taking of backsights will also reveal the presence of local attraction. If such exists throughout the locality so as to make all compass readings affected by unknown errors the traverse may still be carried forward by taking backsights and using the angle differences as in a transit survey. Such a method, however, accumulates error faster than in the ordinary use of the compass since the error in the first course is carried forward in the direction as well as the location of each following course: the accidental error in one course becomes a constant error in those following. The desira-

bility of closing the traverse by tying in to known points every mile or two is well known and becomes especially necessary with this method.

The keeping of an accurate traverse ordinarily doubles the time of getting from one place to another. In thickly wooded or hilly country it is still greater. Much of the time an approximate traverse may suffice until something is found requiring more accurate location. The direction may be kept approximately without effort by occasionally determining the direction of the sun and noting the angle of the traverse to it. The eye can readily follow such an angle with an error of not over five degrees. If walking away from the sun the shadows of the trees will serve as a guide. When the sun is not available the direction of hill slopes or of distant objects may be employed. If it is desired to locate some point with higher accuracy a more precise traverse may be begun and used as a base for triangulating to some determined or readily determinable object. Sights to it from at least three points of the traverse should be obtained, the angles of the triangle should be at least 30 degrees and the object should not be more than a mile distant.

Efficiency in Pacing.

It is of course necessary that every geologist should know his pace accurately and that it should be nearly constant under all reasonable conditions. A tape 100 feet long should be in the possession of every party and the pace, especially of the newer men, should be standardized by having them pace measured distances at different times and over different kinds of ground. Such a test may readily be made a contest by having the pacing done first and seeing who has determined the distance most accurately. The writer has found it advantageous to restandardize his own pace at least once or twice a season. In this way the probable error of pacing over good country can be kept down to at least one per cent.—about 50 feet per mile.

In going up steep hillsides it is often laborious and difficult to pace the same length as on a level road. The pace may then be

shortened to one half with advantage, noting only the footfalls of the right foot instead of both feet in counting the quadruple pace. This half-pace may be made quite accurately by noting the proper distance between heel and toe. If for example the normal pace is 33 inches and the shoes are a foot long, the heel of one foot should fall 4.5 inches horizontally in advance of the toe of the other foot.

Vertical Measurements by Aneroid and Barograph.

An aneroid barometer is the quickest and most portable device for determining elevations. But the barometer, even during constant weather conditions, is subject to daily changes in atmospheric pressure which are equivalent to 50 or 100 feet of elevation, the pressure becoming least in the afternoon. It is subject also to the changes due to the passage of the cyclonic and anticyclonic areas of pressure. The weather conditions may thus cause readings on the same point to differ by several hundred feet in elevation from day to day. Yet a good barometer is extremely sensitive and will record a change of elevation of a few feet. The most common method of eliminating these errors is to tie up on known points at intervals during the day; or to have a man in camp read an aneroid at intervals, as a check to the field man. The errors are then distributed uniformly between the times of the checks. The writer has also known the method to be used of sitting down at intervals and watching for at least fifteen minutes the rate of change of the aneroid. This appeals especially to fat geologists or those who need to smoke at frequent intervals. These methods of eliminating errors at the best do not avail of the full value of the aneroid, since the changes in atmospheric pressure through the day are decidedly irregular. At the worst, there may be no reliable point encountered during the day or no camp helper to read an extra aneroid. Some other method is needed therefore to really utilize the sensitiveness of the barometer. Such a method is described below.

The writer has done considerable work without an assistant on a variety of problems and through several years where rapid

determination of elevations were desired to a closeness of ten feet. For this purpose the aneroid was corrected by the record of a barograph. A suitable portable barograph is the Richards, made in Paris, and costing about thirty-five dollars in the United States, duty paid. This is $7 \times 5.5 \times 4$ inches in dimensions, with handle and wooden sides except for a glass in front. To protect the glass during transportation a brass plate was made to screw on in front and transferable to the back. During such transportation of the barograph the needle must be raised to prevent blotting the record and a small wooden block may be fitted in front of the lifting lever to hold it in place. Arranged in this manner this instrument can be packed readily in a suitcase and has been carried some thousands of miles without accident. It has never been allowed however in the hands of the baggage man and when left standing on hotel bureaus, in order to avoid danger to the barograph, it should be labeled "*Danger. Please do not touch this instrument.*" The range of motion of the recording pen is 2.5 inches, equivalent to between 2,000 and 3,000 feet in altitude, so that in carrying the barograph over mountain grades it must be watched to some extent and adjusted if necessary by means of the key provided for the purpose. The record for the week is nearly 8 inches long, one hour corresponding to .047 inch. The scale is thus seen to be amply magnified. This instrument may be left at the nearest railroad station, or at the hotel or camp, and gives a continuous record of corrections.

To determine the level of the headquarters, Gannett's Dictionary of Altitudes in the United States, Bull. No. 274, U. S. Geol. Surv., 1906, is most valuable.

The relation between the correction in inches on the record and its equivalence in feet will vary with the altitude of the barograph and can be determined from the scales of the pocket aneroid. At sea level 0.1 inch = 88 feet; at 2,000 feet elevation 0.1 inch = 94 feet. A conversion table may be made for rapidly transforming the corrections of each hundredth of an inch into feet. The aneroid should be compared with the barograph at the beginning of the day's work and the time recorded. The

times of all barometer readings made in the field are noted and when working within a few miles of the stationary barograph at its known point the corrections can be directly determined and the true elevations written in the notes at the close of the day, or at any later time. In determining the elevations of points at a greater distance from any known elevation the daily weather maps must be used to supplement the barographic record; since during ordinary weather conditions the barometric gradient may be as high as a tenth of an inch in from 50 to 200 miles.

With aneroid readings corrected in this way the writer has found it possible without any loss of time over the ordinary use of the aneroid to determine elevations to within a single contour interval; correcting the older topographic maps, or measuring elevations in regions not as yet topographically surveyed. Supplemented by a locke level the aneroid enables one to measure the levels of adjacent terraces or hills, frequently without leaving the roads.

The use of the barograph for geological purposes has been thus fully described because apparently its availability is almost unappreciated. It would seem as though many geologic field parties might profit by its use.

JOSEPH BARRELL.

OBJECTS AND METHODS OF PETROGRAPHIC DESCRIPTION.

In nearly all geological reports on mining districts, and many others as well, a considerable amount of space is given to petrographic description. In some cases this descriptive matter is made further use of by indicating its bearing on the solution of important problems; in other cases the reader is left in some doubt as to the exact object in mind when the pages were written. These observations have suggested to the writer that an effort to formulate definitely some of the objects that control petrographic descriptions and the methods which fit them or by which they may best attain their purpose might not be amiss in the present discussion.

For the object in view there is no particular advantage in trying to discriminate rigidly between Petrology and Petrography.

As a matter of fact, it is the broader phases of the *science of rocks* that I have in mind, but the individual rock description is the most important foundation for whatever real substance there may be ultimately to the science. I am therefore especially concerned about the purposes and objects of such descriptions and the most effective methods of recording and presenting the results of petrographic determinations.

No matter how elaborately we may develop petrography, or some special petrographic scheme, so that the niceties of discrimination on particular lines make it possible to classify with precision and confidence, we can never get entirely rid of the fact that rock study is essentially a branch of the great science of geology, and that the ultimate aim is a historical one. The most serviceable description of a rock is one that leads to the same goal, *i. e.*, to the life history of it.

All of the more elaborate classifications tend to neglect this phase in order to be able to apply rigidly criteria of more easily determined character in which there is less of the element of interpretation, and perhaps less of the personal equation. The most perfect one of all, from this standpoint, the "quantitative system" based on chemical analysis, is at the same time one of the most arbitrary and, for the average practical case, one of the least useful in its present form. It is a splendid magmatic classification scheme. But in real life we are dealing not with magmas so much as with the products of magmas which, because of differing conditions, have given rocks that do not usually agree wholly with their theoretical behavior. This gives us in the very beginning a discrepancy between the *norm* and the *mode* which has as yet no explanation. After all the *mode* is the real rock. There is a big field for some one to determine the meaning of this primary discrepancy.

But even here the difficulty is not passed because there are comparatively few rocks that have suffered no subsequent modification. Nearly all have had a life history that is long and complicated and more directly related to other usable geologic data than are the matters of minor chemical makeup. In spite of these limitations, however, I have no quarrel with this method.

It is an eminently satisfactory one for its purpose. But it is only one of the methods and need not be used unless the object of the study demands it. There is a present tendency to overestimate its value.

As a matter of fact the study of rocks is a larger and still more complicated subject. There is to be a *science of the life history of rocks.* This is a phase of the larger science of geology that will never pass. It has to do with great problems, such as origin, successive changes or modifications, as well as the present condition. Classification schemes may well vary. Methods of arranging data and plan of description may well be modified or wholly abandoned without in the least affecting this deeper subject.

Petrography is in large part an applied science. Its most intimately applied bearing is on geology proper and the varied problems of geology. But in a much narrower sense also it is an applied subject. It is making real progress toward its greatest usefulness through studies directly designed to aid in solving special practical problems. There is developing a reasonably accurate discrimination between primary and secondary constituents and textures and structures, and general condition. From them there is occasional fairly successful interpretation of the meaning of these different features. If one could interpret fully everything that a rock carries in its makeup in detail, its whole history could be unraveled and every chapter of any importance to it from the beginning could be written in its description. But, like other phases of geology, some chapters would contain little, and many happenings of very great importance to other types of things may well have been wholly lost in a particular individual. When, however, the life histories of all types of rocks are unraveled, the competent philosophical petrologist ought to be able to throw more light on the actual happenings that have made up the history of the earth than any other specialist of geology. It will be possible for him to go into stages and conditions and processes where neither the paleontologist nor the stratigrapher nor the physiographer can follow. Of course no such perfection is yet attained. But this is the direction of progress.

Judging from the average description of a rock one would be in doubt about many things. It is seldom clear, in the first place, what the object of the description was. It should not be necessary to label it in order to judge. The form and content ought to indicate precisely what the purpose is. Many are plainly faithful attempts to give as thorough and full statements of observations and determinations as the investigator found time to make, and the published description is frankly a record of them, without any other object. Many that seem to fall short of the requirements of such a plan must have had some other purposes governing them, or else they are faulty or incomplete. One is reluctantly led to believe that some descriptions have been written as much to fill up space as for any other purpose. Most descriptions are unwieldy and the essential items in them are not readily located. Even the simplest ones require inspection with some care in order to secure data for comparisons or to note contrasts or to make groupings.

It has fallen to my lot in the past few years to examine many thousand rocks. Most of these examinations have been made for special purposes that clearly did not require an elaborately detailed description or a very complicated classification scheme. Much work with engineers and other practical men has led to the adoption of short cuts to the main point wherever that seemed possible and to the critical separation of observations from inferences, or in any case to the labeling of data so that the quality in that respect could be discerned.

It has been necessary at the same time to teach large numbers of students the elements of rock determination and description. There again the necessities of the case, in securing any adequate efficiency, have tended to the development of schemes with a direct plan suited to the particular type of description or determination needed and some of these have been reduced to the form of blanks that require only the filling in of observations and conclusions. They have saved an immense amount of time in the mere matter of recording data, but this is only a part of their usefulness. Such descriptive outlines have the advantage of showing similar kinds of data always at the same point in the

plan, and, in making comparisons of a large group, the labor of assembling and selecting data for a summary is greatly reduced.

An outline which would serve for all sorts of cases was found to be too complicated for the average use, and this led to the adoption of a series of different forms designed for the commoner kinds of cases. This has naturally led to emphasizing the object and method to an equal prominence with the determination itself. In practical and applied work it is often not at all essential to make elaborate classification distinctions. There are many problems in which petrographic investigation is a most important factor, where it is not necessary to even name or identify half of the mineral constituents. The line of applicable evidence or data may be chiefly structural or a matter of alteration or successive stages of modification or clews as to origin or to the probable field relation.

This long introductory explanation, I fear, has not been nearly so direct or so well suited to the object in view as I am advocating for petrographic descriptions. But a few of the common types of objects and methods will serve better to illustrate the main thesis.

The purposes of petrographic description are as follows:

1. A description leading to a satisfactory field name based on hand specimen determinations.

2. A description leading to a suitable classification based on microscopic examination.

3. A description leading to a magmatic classification based on interpretation of the chemical analysis.[1]

4. A detailed description of all determinable data for complete record.

5. A description leading to an interpretation of the life history of the rock.

6. A description intended to serve only as the foundation for

[1] In regard to (3) above, referring to the quantitative system, it is only fair to point out that it is not nearly as free from speculation and interpretation error as is often assumed for it. The whole analysis is manipulated and interpreted and the classification is based wholly on this interpretation. That it is theoretical and somewhat speculative is shown by the common discrepancy between the norm and the mode.

judgment on some special problem or question essentially of an applied character.

The usual object of a rock study and such description as is most often needed is represented in No. 2 above, *i. e.*, for suitable classification or name. Most descriptive outlines are much too elaborate for this purpose. A single sheet in blank form has been found very serviceable. One that has been used for the past two years with much satisfaction is as follows:

(Form I)

PETROGRAPHIC DESCRIPTION

Date

Collector

I. FIELD NOTES

Original No.

Locality:

Occurrence:

Structural Relations:

II. HAND SPECIMEN DESCRIPTION

General Appearance:

III. MICROSCOPIC STUDY FOR CLASSIFICATION

Texture:

Original Structure:

Secondary Structure:

MINERALOGY (Minerals are grouped for interpretation purposes and are arranged in each group in approximate order of abundance)

(*X*) *Primary* Essential Minerals	(*Y*) *Primary* Accessory Minerals	(*Z*) *Secondary* Alteration Products	(*M*) *Metamorphic* Recrystallization Minerals
(*O*) *Introduced Substances or Mineralization*		(*T*) *Tertiary Changes and Enrichment Effects on Ores* (alterations of minerals other than the primary)	

Special Features

(Including special textural or structural habit, and distribution and proportions of constituents)

Origin of the Rock:

Classification:

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The avowed purpose of such an outline is to develop enough data for suitable classification. But so far as the mineralogic determinations are concerned, it is also serviceable for more special applied purposes. It is therefore what may be called the fundamental description and it forms the basis of most of the other types. Its fundamental items are original *texture* and original *structure* as distinguished from secondary or induced textures and structures which may be elaborated under the heading special *features*. And in addition there is an effort made to discriminate between the *primary* and *secondary* and *introduced* constituents separating them at once so that they are recorded in the appropriate grouping in approximate order of abundance. It is easy in this plan to indicate fully what the basis of the classification name is in a way that allows very rapid review. And if this is the object there is no need of a more elaborate description.

In a form for the life history, listed as No. 5 above, which usually forms a part of the data for special problems as well, the same fundamental outline is used with this addition. There is

much attention given to the quality of secondary or induced textures, structures, and minerals, with suggestions as to the processes and agents involved in developing them. The heading of *special features,* therefore, becomes much more prominent and is subdivided. The classification based on interpretation leading back to original condition is given, and then a heading is added that may as well be called *life history.* It includes origin, primary condition, subsequent stages in modification with attempt to indicate connections with the geologic history of the field, and finally a corrected classification based on present condition. When the time comes that the meaning of the discrepancy between the norm and the mode, now so troublesome in the quantitative system, is explained, then it may also throw light on and extend the life history.

(Form II)

ADDITIONAL MICROSCOPIC STUDY FOR LIFE HISTORY

A. Critical Petrographic Data.
Mineral habit, association, relations and modifications.

Paragenesis.
Structural modifications, sequence, and meaning.

B. Life History (an Interpretation).
Origin (with classification based on primary condition).
Subsequent stages (indicating processes involved and connection with local geologic history).
Corrected classification (based on present condition).
Summary.

The Quantitative System Scheme, listed as No. 3, may be outlined somewhat as follows.

(Form III)

CHEMICAL STUDY FOR MAGMATIC CLASSIFICATION

Rock ..... From .....

Analysis made by .....

Place .....(date).....

Analysis *Synthetic Recast*

	Per Cent.	Mol. R.								
SiO_2										
Al_2O_3										
Fe_2O_3										
FeO										
MgO										
CaO										
Na_2O										
K_2O										
H_2O										
CO_2										
TiO_2										
P_2O_5										

Recast Mineralogy (The norm)

Formula. Mol. wt. Mineral. Norm.

Comparison with the mode:

Quantitative classification:

Class: $\frac{Sal}{Fem} = \ldots\ldots = \ldots\ldots$

Order: $\frac{Q}{F} = \ldots\ldots$ $\frac{L}{F} = \ldots\ldots$ $\frac{P+O}{M} = \ldots\ldots = \ldots\ldots$

Rang: $\frac{K_2O + Na_2O}{CaO} = \ldots\ldots$ $\frac{CaO + MgO + FeO}{K_2O + Na_2O} = \ldots\ldots = \ldots\ldots$

Sub-rang: $\frac{K_2O}{Na_2O} = \ldots\ldots$ $\frac{MgO}{FeO} = \ldots\ldots = \ldots\ldots$

Recast by.....

No. 6 is the catch-all for all sorts of applied problems. It gathers from all of the other types of description those items that may be used in reaching conclusions and as soon as the facts are assembled proceeds at once to the argument that promises as definite a conclusion as may be drawn. In illustration of the simplicity of the data needed in some of these cases I cite one that came from a mining district in Alaska some time ago. The engineers have found time to study the local geology in addition to their other work. Two formations, one finer texture than the other, presented field conditions that puzzled them in this wise: It was not clear to them whether one was simply the sheared equivalent of the other or an entirely different rock. The types of rocks were such that the point was not as easily settled as usual. In making this description and drawing a conclusion it was necessary only to determine the texture and structure and the chief constituents, make a critical comparison especially as to the arrangement of constituents in the finer rock and consider the possibility of finding them in such relation if it were to be regarded as derived by shearing from the other. In the coarser rock there were many quartz grains amongst the more prominent constituents, yet in the finer one there were no areas of aggregates suggesting derivation from such units. On the contrary the distribution of constituents was as complex as in the other rock. One is compelled to conclude that the evidence pointed toward original difference in the two formations and later field and chemical work has supported this conclusion.

An outline for applied cases will necessarily vary somewhat with the nature of the problem. But it will always include a considerable portion of the fundamental description (Form I), followed by a statement of the particular question belonging to the case, an assembling of the data bearing on it, and finishing with the argument and conclusion. The additional items are usually the following.

(Form IV)

PETROGRAPHIC PROBLEM NO.

Date

Collector

Original mark

I. GENERAL DETERMINATION

Texture:

Structure:

Mineralogy:

Primary	Secondary	Metamorphic	Introduced

Classification:

II. THE QUESTION IN THIS CASE

Comment of the collector:

III. APPLICATION OF PETROGRAPHIC FACTORS

Determinable related data:

(Amount of detail to be gauged to suit the requirements of the problem)

Argument:

Conclusion:

Suggestions for additional investigation:

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In addition it is often advisable to accompany a description by a photomicrograph or drawing as an aid in presenting special characters or in making comparisons. This is best done on a separate sheet and is more effective if it immediately follows the regular description and carries, as a label, a concise statement of what it is intended to show. For this purpose the upper half of the page or sheet is left blank for attaching the print, and the lower half carries an outline for the explanation, which should have room in the average case for several items.

(Form V)

PHOTOMICROGRAPH OF ROCK NO.

Taken with .....light
Magnification about .....diameters

Showing:—

(a)

(b)

(c)

(d)

(Items of special textural, structural and mineralogic detail seen in the photomicrograph are to be listed above and if necessary correspondingly marked on the print)

These are all legitimate types of petrographic descriptions, and one is not necessarily a better form than another. They are simply different and they are so because the purposes are different. All of them belong to petrography. They are the methods or plans of description. They are also essentially different petrographies. Some deal with data that may be grouped into a system more successfully than others, but that they are on that account more important or more useful or more scientific does not necessarily follow. The more important thing is to see that the right one be used for the purpose in hand and that one allow himself to be led but little from the most direct line of development to the object of the rock description.

CHARLES P. BERKEY.

NOTE TAKING.

Sir: Nothing is of more importance with the field geologist than the careful taking of notes. These should express in full the observations of the worker, with the impressions and conclusions coming from them that are worth recording. But if others are like myself, many first impressions have no value, and should not be given space in the notebook, for they are trash in the way of preparing reports, and may be misleading. For this reason, I have of late years made it a practice to look carefully into a feature that has come under my observation for the first time, before making any notes. I have found that this reduces the volume of the notes, but gives value to those taken.

Yet, especially in regions whose geology I am not familiar with, the impressions from one observation, however cautiously recorded, may be entirely eliminated, and their place occupied by others growing out of subsequent observations. If the first impressions demanded a note, the subsequent ones that replace them make a note doubly important. But without some system in note-taking, the contradictory notes are lost in a maze of others; and in the consequent loss of time when it comes to writing the report, one loses patience with himself if the notes are his, and with another if they are not.

One way of keeping track of contradictory or related notes is to number all notes consecutively. This makes cross reference an easy matter. For example, if note 57 annuls or relates to note 23, at the end of the former, simply say "See note 23," and then turn to the latter and say "See note 57." While one is in the field, with notes and previous observations fresh in mind, it is a matter of only a short time to find any note that may be desired. But before the report is begun, the position of the notes is forgotten, and without some such device as the above, much time is lost in searching for them. If one is using another's notes, a system of cross reference is all the more desirable, and the one suggested will be found to work well.

A. H. PURDUE.

FIELD METHODS IN PHYSIOGRAPHIC GEOLOGY.

Sir: The following are a few general principles regarding the preparation for field work which apply as well to geologic as to physiographic work. They refer more particularly to that great majority of field problems which are not wholly new, but which have been described to some extent in the literature and about which more or less definite views have been entertained. In the case of a wholly unknown field containing new problems, some of the following paragraphs would not be at all pertinent; while others would apply only after the field work was far enough advanced to furnish some facts upon which to speculate.

It is my conviction that the method of collecting and recording field observations is less important than the method of preparing for the collection of the data. It is, of course, necessary that one should record his notes in a clear and systematic manner, and this becomes a matter of special importance if they are to be turned over to some superior who must depend upon the notes of several assistants in compiling a report. But in general keen observations, although unsystematically recorded, may in course of time be deciphered by a sufficiently patient superior; while faulty or incomplete observations due to imperfect preparation for the field work are of little value no matter how easily deciphered. For this reason I have laid less stress upon the method of collecting field data than upon the preparation for field work, although I recognize the importance of both.

COLLECTING FIELD DATA.

In looking over my field notebooks, I am unable to find much evidence of method in keeping physiographic records. It should be pointed out, however, that my notes are usually written for my own personal use, and while I have not felt the need of greater system in keeping them, there is no doubt that in case they had to be used by another, that other would feel that the need was urgent. In working out the structural geology of a region as a basis for physiographic work, I have found a definite system essential to the best work, and have made use of a modification of Campbell's

profile traverse method[1] in some regions and of the method devised by Kemp[2] in others. Any further method in my way of collecting field data consists in an attempt to put into practice certain principles which are not novel but which may be important enough to merit a brief consideration in the following paragraphs.

On a later page attention is called to the enormous economy in time and trouble which may be effected by securing a proper mental equipment before entering the field. But at the critically important points in the field there should be no economizing of time. It seems to me essential at such points not only to see and record all the facts fully and accurately, but also to try to explain these facts on the basis of every possible hypothesis. With the facts before him one can perhaps invent new hypotheses or modify old ones, and time should be taken on the spot to commit to writing such new ideas as the phenomena in view may suggest. One cannot make his original notes too complete and elaborate. I should strongly advise against the practice of making brief headings on the most important subjects, with the idea of writing these up more fully at the close of the day. It may occasionally be a necessary evil, but there are two good reasons against it. First, no matter how fresh one's memory may seem, it is never wholly to be trusted. In the evening one writes what he thinks he saw, and this sometimes differs appreciably from what he really saw. In the second place, in writing up notes at night it is a rare man indeed who does not find a number of points about which he wishes further information—points he has forgotten, points he failed to notice, or things he noted casually at the time but now finds are vital to his conclusions and therefore need fuller examination with his conclusions in mind. If the notes are written out fully with the field facts right before him, each of these points may be attended to as it arises. The more carefully one describes the phenomena in view, the more of them does he see.

A device which I have found of much value is the writing out of such parts of the final report as I could while still in the field.

[1] *Trans. Inst. Mg. Eng.*, Vol. 26, pp. 298–315, 1896.
[2] Kemp, *Geol. Soc. Am.*, Vol. 16, pp. 411–418, 1905.

For this work evenings and stormy days offer some time. The extent of such work which is practicable will often be not great, but even a moderate amount has proved valuable in suggesting lines of inquiry, places to see, and other points which it is desirable to have arise while the field is still accessible. Every field worker must have had the experience of wishing to go back into his field to look up many points which did not occur to him until he was writing his report. Any device which will reduce the number of such points is worth while.

Another matter seems to me of the highest importance. In writing field notes, I try to make a clear distinction between facts and theories, between things actually seen and things inferred. We have many of us seen notebooks in which it was not possible to tell precisely what the observer actually saw because he simply states that certain things occur. The grounds for the assertion or conclusion should be plainly indicated, and a clear line drawn where direct observation ends and logical inference begins. If field workers would exercise due care in this important matter, perhaps there would be fewer reports published in which it is impossible to separate the author's observed facts from the author's opinions.

Thus far we have given attention largely to the manner of observing and recording data in the field. To my mind, however, the success of field work depends primarily upon a matter of more fundamental importance, which I may call the

PREPARATION OF THE MENTAL FIELD EQUIPMENT.

It would seem axiomatic that the first thing to be done in preparing for field work is to make one's self familiar with all the available information on the region, particularly with the literature relating to the general geology and physiography, and to the special problem to be studied. Yet I have heard one of our prominent geologists urge that a man should not read the literature on a region to be investigated until after he had completed the field work and returned to the office. His argument was that the investigator should enter his field with an unbiased mind to the

end that he might observe all the phenomena impartially and so be free to reach whatever conclusions they might suggest. It is certainly important that the field worker attack his problem with an unbiased mind. But I have not observed that ignorance is conducive to impartiality of judgment. The men who have impressed me as being most broad-minded and impartial in matters geologic and physiographic, the men most hospitable to new hypotheses or alternative explanations, are men known among us for the breadth and scholarly character of their learning.

In the January issue of ECONOMIC GEOLOGY Professor Irving has stated the economic advantages accruing to the field worker from a knowledge of the literature of his region. Much reconnaissance work and the laborious study of many details may be eliminated by an examination of what has already been accomplished by previous workers in the district. To this argument I would add another, which seems to me of even greater importance. The powers of observation are enormously sharpened by a study of the literature. What field worker has not had the experience, upon returning from the field, of encountering in some article or report information which makes him wish for another chance to visit the region and make additional observations on certain points? The greater the pre-field work preparation, the fewer the post-field work regrets.

In physiographic work I have found a knowledge of the literature so great an aid to observation that such mental impressions as I could carry into the field from my reading seemed insufficient. On the other hand, it is not practicable to take any considerable number of books into the field, particularly when the nature of the work compels travelling with a camp equipment. I have therefore adopted the expedient of preparing abstracts of reports as I read them, these abstracts being written in a fine hand in notebooks easily carried in the pocket. On one field trip involving much travelling over a large area I carried rather full abstracts of about 130 articles and reports, written in 9 booklets, the total weighing a little less than one pound. Each evening the abstracts relating to places or problems to be considered next day

were reviewed. Incidentally such abstracts are of great value when one comes to write reviews of the literature for the final published report.

While reading the literature and writing the abstracts, many questions arise in one's mind as to the interpretation of the facts observed by a given writer, and there occur to one many suggestions as to things to look for in the field, important points to visit and examine, and alternative hypotheses worth testing on the ground. These ideas constitute a valuable part of one's mental field equipment; and if the area to be visited is extensive, or the problems to be investigated either numerous or complex, the man who can carry all his valuable ideas safely in his head must possess an abnormally retentive memory or a lamentably small stock of ideas. Unable to claim the first, and unwilling to admit the second, I make it a rule to write down all questions and suggestions as they arise, in a properly labelled notebook similar to those in which the abstracts are kept. This book of "Questions and Suggestions" is frequently reviewed throughout the field work, additions are made to it as the progress of the work suggests new points, and from it much valuable assistance is derived.

It may appear that in case a problem is very broad or very complicated and the literature extensive, the accumulation of abstracts, questions and suggestions might become sufficiently great to embarrass the busy field worker who, at the end of a hard day's work and part of an evening spent in amplifying notes, has neither the time nor ambition to look through a half dozen booklets of abstracts and a dozen pages of questions and suggestions to see what might prove of possible value for the next day's work. To avoid this danger I adopt two devices. The first is to group together in a single booklet, as far as practicable, those abstracts which will be of special value in a certain part of the field. Thus one abstract relating solely to the shorelines of Florida will not be in a different booklet from another abstract of similar content; although an abstract relating to the entire eastern coast of the United States, and containing some information on the Florida coast, might have to be sought for in another booklet. It is not

often practicable to arrange such abstracts in an ideal manner; but even where a large number are involved it is possible, by exercising a little foresight, to group them as they are written in order that the labor of finding a given one is reduced.

The second device is to devote a few hours, preferably at the beginning of the field season or just before, to arranging lists of references to abstracts, suggestions, questions, etc., for each important point to be visited in the field. For example, under "Cabezon Peak" would be jotted down any questions or suggestions that had arisen regarding that place, and also a brief statement of the main features of any abstracts of articles relating to it; or, if the abstracts were long and important, merely cross-references to the booklet in which these abstracts would be found.

It may seem to many that a man is sufficiently prepared for field observations when he has read and abstracted the literature of his subject, and recorded such questions and suggestions as have occurred to him while revolving the matter in his mind. But I believe he will fail to see all that he might see, and fail to accomplish all that he might accomplish, unless he goes more deeply into his subject before he goes into the field. He ought not to be content with the theories advanced by his predecessors to account for the facts they observed, but must if possible invent new hypotheses which will explain these facts. He must make a special, serious effort to imagine all possible conditions under which the phenomena described in the literature might be produced, and thus apply Chamberlin's method of "multiple hypotheses" in his attempt to account for these phenomena. This requires a greater mental effort than is involved in reading the literature or in merely thinking over points and questions which are suggested by the reading. But the results are worth the trouble. Nothing conduces more to an impartial examination of the field phenomena than the carrying in mind of several hypotheses, each one of which the field worker desires to test by all the facts available. Nothing so sharpens the eyes of the observer as the continuous, conscious effort to see all the facts which might bear on the validity of each of several interpretations. Such an observer notices things which would never attract the attention of

another. No man ever records, or even *sees* all the phenomena before him in the field. Out of the mass of details certain things impress themselves upon his mind because of their size or their significance. The rest may form a passing image on the retina, but makes no lasting impression on the brain; the man is mentally blind to much that is before him. The extent of his blindness varies inversely as the number of facts which appear significant to him; and the number of significant facts in turn depends on the number of hypotheses entertained which these facts are capable of proving or disproving. The man who enters the field "with his mind a blank, free from all theories, and ready to see anything there is to see," goes in with his mental eye (the best eye he has) tight shut.

But the work of mental preparation must not stop with invention of multiple hypotheses if the worker is to have the best equipment for collecting field data. The consequences of every hypothesis must be deduced as elaborately as possible, so that the investigators may know what facts ought to be found in the field in case each hypothesis is true. This will add, to the list of "reported phenomena" already described in the literature, certain "expectable phenomena" which the investigator will then look for in the field. The advantages of this kind of preparation are obvious. Armed with a catalogue of phenomena, one group of which should be found if one hypothesis be true, another group if another hypothesis be true, and so on, the investigator will not only be impressed by the significance of many facts which have escaped the attention of others but will deliberately search for other facts which do not stare one in the face, but which may be discovered by the man who knows that they are worth hunting for. Furthermore, the man who is well equipped with multiple hypotheses and with a catalogue of their respective consequences, can effect a great economy in time, money and labor in his field work. If it be essential for him to get the most important facts at the least possible expense of time and money, he can compare the groups of phenomena to be expected under each hypothesis, and eliminate from consideration those phenomena which are common to all groups, concentrating his attention on the "critical

phenomena," *i. e.*, those of critical value in determining which hypothesis is correct.

There is another advantage in the use of the method of multiple hypotheses as a preparation for field work. It is the greatest safeguard against that fallacy into which so many field workers fall, namely, the idea that a theory which explains the observed facts is correct. A large proportion of the serious errors in geological and physiographic work which have come under my notice have been due, not to poor powers of observation, but to the very evident fact that the author adopted some theory which occurred to him as explaining all the facts he had observed, and made no conscious effort to entertain alternative interpretations, deduce their consequences, and seek new facts of critical value. The best field worker is the man who can invent the most hypotheses, deduce the consequences of each most accurately and fully, and test the deductions in the field most effectively.

DOUGLAS W. JOHNSON.

Sir: It might be of interest to your readers to learn that the deductions of Messrs. Ch. Almer and E. S. Bastin in the article "Metallic Minerals as Precipitants of Silver and Gold," ECON. GEOL., Vol. VIII., No. 2, find an apparent proof in an occurrence at the Old Dominion Mine of Globe.

On the ninth level of this mine occurs in the east-orebody a zone where flakes of native silver occur rather freely on almost pure chalcocite, sometimes accompanied by small sheets of native copper, along seams in the chalcocite. The horizon belongs more or less in the oxidized zone, as adjoining the chalcocite, which occurs in intrusive basic dikes. Copper carbonate and silicate are predominant in the quartzitic-sedimentary constituents of the broken vein or fault material. These change not far below to native copper and cuprite, while the chalcocite in the intrusive dikes remains the main commercial mineral for several hundred feet more in depth, to change in our lowest workings to a combination of pyrite, chalcopyrite and bornite with more or less micaceous hematite.

WM. L. TOVOTE.

Sir: While engaged recently in describing some of the disseminated copper deposits of Arizona, I had frequent occasion to refer to the unenriched valueless pyritic material which in general underlies the ore. Locally such material is termed "primary ore"; but it is not, properly-speaking, *ore* nor is it likely by any improvements in mining or milling to be made available as ore. Moreover, the term "primary ore" has useful application to numerous deposits of commercial importance and should be reserved for such usage. In attempting to meet these objections I devised the term *protore* and found it so convenient in practice that I venture to suggest its adoption to designate the valueless material which generally underlies ores formed by sulphide enrichment and which would itself be converted into ore were the enriching process continued to sufficient depth.

F. L. RANSOME.

A CORRECTION.

Sir: Mr. E. Gibbon Spillsbury has kindly called my attention to the fact that the word "cementing" which in my review of Mr. and Mrs. Hoover's translation of Agricola (this journal, Vol. VIII, No. 5, p. 510) I too hastily assumed to be an error for "smelting," is used with its correct technical significance. Not being a metallurgist, I was unfamiliar with this usage and freely acknowledge my mistake.

F. L. RANSOME.

REVIEWS

The Geology of the Waihi-Tairua Subdivision, Hauraki, Auckland. Bulletin No. 15, Geological Survey Branch, Department of Mines, New Zealand. By J. M. Bell and Colin Fraser.

This bulletin marks a considerable advance over most of the official reports describing Australasian deposits, and one notes with regret that both of the writers have lately left New Zealand to reside in London. The paper includes 192 pages, three topographic and three geologic maps in the pocket, with numerous colored maps and sections set in the text. The area described is approximately the east half of the Hauraki peninsula proper, and has an area of 442.9 miles. Although mining districts in this region are numerous, the Waihi district is of the greatest interest economically. The gold production is over fifty million dollars, of which the Waihi has produced about nine tenths. All of the consolidated rocks are igneous. To the northwest of the area, however, Jurassic and older sedimentary rocks appear. The oldest volcanics consist of andesitic and dacitic lavas and breccias. These are followed by a second series, differing but slightly in petrological character. The youngest series of volcanics is mostly rhyolitic in character. The rock-complex is intruded in various places by dikes of andesite and dacite.

In the Waihi gold field, which as stated above is the most important district, the surface is nearly flat and from 250 to 400 feet above sea.

The oldest rocks visible in the area are pyroxene dacites, and these are of prime economic importance, since they constitute the auriferous series. These dacites have but a limited development at the existing surface. They outcrop in only two small areas, which together measure about 320 acres. The more important outcrop forms the well-known Martha Hill, which is wrapped around on east and west by later barren rhyolites, and on the west by later andesites. At a depth of about 950 feet below the plains, mining exploration has proved that the area covered by the dacites is not less than 600 acres, and it may be considerably more. As greater depth is attained a much more extensive development of these rocks may be anticipated.

As in all the Hauraki vein-bearing areas, hydrothermal alteration (propylitization) has profoundly affected these old dacites; and even specimens of dark color, which appear fresh to the casual observer, prove when examined microscopically to be considerably altered. Apparently

a boss of dacite of fairly large dimensions has intruded an earlier complex of rudely bedded flows, and it is even probable that the whole of the vein-formation and ore-deposition at Waihi owes its origin to the existence of this dacitic intrusion. In mapping it was not practicable to separate the intrusive dacite from the dacite flows.

The volcanics of the "Second Period" underlie to an unknown lateral extent the rhyolites of the plain. Although the second period andesites are altered by hydrothermal action they are apparently devoid of quartz veins.

The rhyolites of third series of volcanoes (probably Pliocene) form the plain east and west and south of Waihi. None of them is vein-bearing in the vicinity of Waihi. Auriferous-quartz veins occur, however, in the spherulitic rhyolite at Waihi Beach some six miles away.

The deposits are large irregular replacement veins in the older series of intrusive and extrusive dacite. The veins are branching and closely spaced. The larger ones are nearly parallel and on level 4 of the Waihi mine there is a suggestion of conjugation. The ore is the product of at least three different impregnations by mineral-bearing hydrothermal solutions. These, in order of occurrence in time, are as follows: (*a*) Impregnation resulting in the deposition of carbonates, mainly manganiferous calcite; (*b*) impregnation resulting mainly in the deposition of quartz and the various ore minerals (sulphides, gold and silver, etc.); (*c*) impregnation of minor degree compared with (*a*) and (*b*), resulting in the deposition of gold-silver-bearing sulphides with some quartz, carbonates, etc. Changes have been effected in the primary ore by waters migrating from the surface, particularly in the upper horizons.

The barren or low-grade unoxidized vein matter consists principally of manganiferous calcite and quartz, with sheeted or brecciated wall-rock in various stages of silicification. Small sporadic patches of sulphides, mainly pyrite, are in places not uncommon, there being every gradation from low-grade vein matter to ore. Pay-ore occurs from wall to wall over widths ranging up to 80 feet or 90 feet. The gold and silver is, as already stated, almost invariably associated with sulphide-bearing material, or its oxidized equivalent.

The sulphide ore consists in general of a gangue of quartz, manganiferous calcite, and mineralized propylite, with a variable percentage of sulphides—pyrite, sphalerite, galena, chalcopyrite, and argentite—and accessory minerals. The sulphides even in the lowest levels are reported to amount, on the average, to about 4 per cent. of the ore only. In the adjoining Waihi Grand Junction Mine they are said to constitute from 8 to 10 per cent. of the ore treated.

Selenium is obtained in refining the Waihi bullion. No definite selenium mineral has yet been detected in the ores, but the results of analyses

lead to the conclusion that the selenium partially replaces the sulphur of certain sulphides, and it is not improbable that selenide of silver and even that of gold may be present.

A white waxy-looking material, which resembles a kaolinite, is of not infrequent occurrence as reniform scales in vugs and cavities, and as films intercalated with crustified ore. This, as analysis indicates, is almost pure silica.

Oxides of nickel and cobalt are not infrequently associated with the manganese-oxides, and together constitute in places over 1 per cent. of the mass.[1]

In connection with the formation of veins at Waihi, considerations of the form and disposition of the vein fissures, of the fact that the original apices of many veins are still existent, also of the character of the ore exposed from the surface to a depth of 1,000 feet, lead to the conclusion that the ore is mainly a product of primary deposition from heated ascending aqueous solutions. It has already been indicated that there are evidences of a rejuvenation of ore-bearing solutions having effected the deposition of sulphide ore within the main mass of earlier formed ore. These later banded sulphides, however, differ but little in chemical or physical character from those of earlier formation, and the parent solutions probably had a common origin.

With regard to these sulphides, Morgan[2] remarks, "The first sulphide ore found in the Waihi mine at the second level on the foot-wall of the Martha lode was of high grade, averaging 1 oz. to 2 oz. of gold and 30 oz. to 60 oz. of silver to the ton. The richest portions assayed up to 25 oz. gold and 1,000 oz. silver per ton."[3].

Comparing the Waihi deposits described in this paper with the Tonopah deposits described by Spurr, one is impressed with the many similar features of the two regions. Both groups of deposits are in igneous rocks of comparatively late age, nearly related in composition; both are capped in places by later barren rocks. The ores of both carry carbonates and adularia, and the proportion of sulphides to gangue minerals is low in the ore of both districts. Tellurides and selenides are present in both, and the lists of ore minerals are closely similar, although the proportions of the minerals present show considerable variation. Hydrothermal alteration, as already pointed out by Finlayson, is closely similar—silicification, sericitization, and development of adularia and carbonates being the dominant hydrothermal processes in both regions.

The character of the wall rock alterations, the presence of hot springs not far from Waihi now depositing carbonate, the association with a

[1] *Loc. cit.*, p. 139.
[2] P. G. Morgan, "The Hauraki Goldfields," *N. Z. Mines Record*, Vol. 8, p. 465.
[3] Bull. No. 15, p. 141.

particular intrusion of igneous rock (dacite), lead to the conclusion that the deposits were formed by ascending hot waters.

"Irrespective of the elevation of vein-outcrops, little payable ore (excepting at Waihi) has been mined from depths exceeding 500 ft. below the existing surface. The downward limit of the pay-ore mined appears, therefore, to have conformed roughly to surface-contours."[1]

In the Waihi mine, as shown by Finlayson, the richer zone is likewise related to the surface. Bell and Fraser consider this relation to be in the main dependent upon conditions of original deposition. Analyses of the underground waters show the presence of chlorine and the ores carry considerable manganese. One would suppose that conditions have been favorable to gold enrichment. While the writers recognize some instances of downward enrichment, they apparently attribute the distribution of gold and silver in the vein to primary deposition. They recognize in the unoxidized ore three periods of vein formation. The earliest gave enormous deposits, consisting largely of manganiferous calcite; a later period is represented by smaller veinlets in places cutting the calcite veins. These veinlets carry quartz sulphides, gold, silver, etc. Still later, gold and silver bearing sulphides with some quartz and carbonates were deposited. The ore of each of these three periods of vein formation they regard as a deposit of ascending solutions.

W. H. EMMONS.

[1] *Loc. cit.*, p. 65.

SCIENTIFIC NOTES AND NEWS

INTERSTATE COÖPERATION ON FUNDAMENTAL PROBLEMS.—Coöperative investigation of the Mississippian formations of the Mississippi valley states will begin immediately as a result of an important field conference which was held October 10–12 in Missouri. The following states were represented: Arkansas, Purdue; Illinois, DeWolf; Indiana, Barrett, Beede; Iowa, Kay; Missouri, Buehler, Hughes; Ohio, Prosser; Oklahoma, Ohern, Snider; Tennessee, Purdue. The U. S. Geological Survey was represented by David White, Chief Geologist, and W. H. Herron, Geographer in charge of the central section.

The Mississippian formations measure approximately 2,000 feet in the Mississippi valley. Independent work at various times in the past and in various states has resulted in great confusion in the stratigraphic units and in formation names. The evils of independent work in adjoining states without due regard for work already done, or in progress elsewhere, will be eliminated in the future if the present coöperation is successful. A directing committee consisting of H. A. Buehler of Missouri, G. F. Kay of Iowa, and A. H. Purdue of Tennessee was authorized to confer with the Chief Geologist of the U. S. Geological Survey and to begin an active campaign at once.

G. W. CRANE, formerly of the Missouri Geological Survey, has become geologist for the Chief Consolidated Mining Company of Eureka, Utah. His investigations will include a study of the geological structures and the occurrence of the gold-silver-lead ores of the Tintic district.

AT THE LAST MEETING of the Council of the Institution of

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

Mining and Metallurgy, England, F. H. Hatch was elected president of that institution.

F. M. HANDY, of the State College of Washington, spent the summer in the western part of Washington doing geological work in connection with the coal deposits in the Mt. Baker district and in Lewis county.

DR. SOLON SHEDD, head of the department of geology of Washington State College, devoted the recent summer to the collection of data for the preparation of a relief map of the state of Oregon. This work was done in connection with the Oregon Bureau of Mines.

THE WEST VIRGINIA GEOLOGICAL SURVEY has recently issued a new Detailed County Report on Monongalia, Marion, and Taylor Counties. West Virginia. It may be obtained by application.

REPORTS ON PORTIONS OF ALBERTA, New Brunswick, and Hungary have recently been made by the Associated Geological Engineers of Pittsburgh. This organization is at present engaged in an examination of oil properties in the state of Vera Cruz, Mexico. This work is in charge of Mr. L. G. Huntley. Mr. L. B. Smith is examining supposed oil properties in the West Indies. Frederick G. Clapp has returned to Pittsburgh and is preparing foreign reports on oil and gas.